Airplane Cabin Leakage Study

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Airplane Cabin Leakage Report

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1. Executive Summary

V-COMM has performed an extensive study to measure the signal path leakage through the cabin of two commercial aircraft, a Boeing 767-200 and 737-200, for both Cellular and PCS bands to assess the impact of airborne handset and pico cell operation on terrestrial wireless networks. For these airplane leakage measurements, V-COMM conducted measurements along radials at different distances and azimuths from the aircraft for antennas positions at window seats, aisle seats, and pico cell antenna locations.

These airplane cabin leakage measurements were performed in April of 2005 at an airport facility with vast open areas to facilitate measurements in areas without reflections from nearby structures. In addition, measurements were made in the same locations without aircraft present, to remove the ground reflection components of the measured signal data. Therefore, the results presented in this study show the signal path leakage through the aircraft cabin and outside the aircraft in the directions of the terrestrial networks.

The worst case location for the signal leakage observed for the window seat locations and azimuths that were broadside to aircraft. At other azimuths that are not broadside (greater than 25 degrees from perpendicular) to the aircraft, and at other interior locations, the signal leakage decreases considerably.

For airborne handsets operated by passengers sitting at window seats on the 767 aircraft, the signal leakage through the airplane cabin is relatively unaffected (0 dB loss) by the airplane window. For the 737 aircraft the window presented a slight increase in signal strength (gain) on average in both bands on the order of 3 to 4 dB. We believe that the signal gain of the 737 aircraft is due to the unique properties of the 737's window construction, the reflections inside the cabins and window structure, and the orientation of antenna in the aircraft. Given that this was not the case for the 767 aircraft, gain through the window of an aircraft will vary from aircraft model to model. Therefore, to assess the impact of airborne handsets used aboard commercial airplanes the signal path leakage for many airplane types should be studied to gain a good understanding of the respective airplane leakage properties and propagation issues. Also, it should be noted that similar results (signal strength gains) for the 737 aircraft were measured by other parties, as indicated in this report.

For the partially blocked azimuths from the window seating locations the average reduction in signal leakage for the 25 to 30 degree azimuths (referenced to perpendicular to the aircraft) are 3.5 dB for Cellular and 8 dB for PCS for both aircraft, as compared to the worst case broadside azimuth. Also, the average reduction in signal leakage for the 45 to 60 degree azimuths are approximately 11 dB for Cellular and 12 dB for PCS for both aircraft. The average reduction in signal for all of the partially blocked views (between 25 to 60 degree azimuths)

for both aircraft are 7 dB for the Cellular band, and 10 dB for the PCS band, as compared to the worst case broadside view.

For handsets operated by passengers sitting at aisle seating and for the pico-cell antenna locations, the signal path leakage is lower (greater isolation) than the window seating areas.

For the aisle seat locations, the signal strength decreased through airplane cabin by an average of 8 dB for the Cellular band and 11 dB for PCS band, when considering angles of the horizon to 40 degrees below. When considering the incident angles of 10 to 30 degrees below the horizon (which are the worst case incident angles for typical base station antenna patterns), the signal from the pico cell location was attenuated by the airplane cabin about 6 to 10 dB for the Cellular band, and 5 to 10 dB for the PCS band depending on the aircraft. These incident angles should be used for assessment of the interference potential of onboard pico cell operations because they represent the worst case incident angles toward the terrestrial networks, and also coincide with the worst case incident angles of typical terrestrial base station antenna patterns.

For the pico cell antenna locations studied, the signal strength decreased through airplane cabin by an average 15 dB for the Cellular band and 14 dB for PCS band, when considering angles of the horizon to 40 degrees below. When considering the vertical angles of 10 to 30 degrees below the horizon, the signal from the pico cell location was attenuated by the airplane cabin about 8 dB for the Cellular band, and 6 to 10 dB for the PCS band depending on the aircraft.

For interference analyses assessing the impact of airborne handset operations using cellular or PCS spectrum the worst case signal leakage (through the airplane cabin toward the terrestrial wireless networks) results should be used. As indicated in this study, the worst case signal leakage results are shown to occur at the window seat and broadside azimuths. In these cases, the approximate loss through the airplane cabin can be assumed to be approximately 0 dB for the Cellular and PCS bands, based upon the measurements for the Boeing 767 airplane. In addition, in some cases the signal will experience an increase in signal strength on the order of 3 to 4 dB, when propagating through the cabin window, as observed for the Boeing 737 airplane. For interference analysis assessing the potential interference from pico-cell transmissions in the airplane cabin, the signal path loss at least 8 dB for Cellular and 6 to 10 dB for PCS should be used.

2. Introduction

V-COMM has performed an extensive study to measure the signal path leakage through the cabin of two commercial Boeing airplanes for both Cellular and PCS bands.

These airplane leakage measurements were performed on two airplanes owned by United Airlines. United Airlines provided V-COMM access to these two aircraft at a non-commercial airport that is used for aircraft maintenance and storage in Victorville, CA. Therefore, this facility was particularly suitable for our measurement purposes, which allowed us to access and perform measurements on the aircraft without operational scheduling issues and offered vast open areas around the aircraft to perform radial testing without the introduction of reflections from large reflecting structures such as buildings or other airplanes.

This report contains the results of the study performed by V-COMM. These measurements were performed in April of 2005.

3. Test Descriptions and Methodology

3.1. Test Setup and Equipment Used

Two airplanes, a Boeing 767-200 and 737-200 were used in this study. The airplanes were located on an isolated taxiway at the Victorville, CA. In both cases, testing was performed on the starboard side of the aircraft (right side facing front). The areas surrounding the airplanes and measurement areas were clear of any reflective objects and structures, which ensured that minimal reflections from nearby structures will impact the results of these measurements.

Cellular and PCS continuous-wave transmitters were used onboard the airplanes to simulate the transmission of Cellular and PCS handsets (see Figure 3 below). Cellular and PCS measurements were taken at each measurement location by using band specific half-wavelength unity gain dipole antennas,[1] connected to the test transmitter through 100 feet of LMR-400 cable for the transmit antennas and 10 feet of RG/U 142B cable at the receive antennas. The transmit antennas was positioned via a clamp and gooseneck assembly to establish the desired transmit antenna position (see Figure 7 below) within the cabin of the airplane.

A Rhode and Schwartz FHS-3 Portable Spectrum Analyzer was used to establish the same reference RF power level at the input to the transmit antennas for all tests with the use of a calibrated pad. The selection of the transmit frequency for the Cellular and PCS bands were coordinated with the local wireless providers serving the area. The receive antenna was positioned 5 feet above the ground using a wood and PVC stand. The insertion loss of the receive cable for both frequency bands has been compensated for (normalized out of measurements) for the receive measurements.

For each measurement point, the spectrum analyzer was connected to a receive antenna’s base at 5 feet above the ground (see Figure 5 below). The spectrum analyzer was configured as shown in Table 1 below. For all measurements, the spectrum analyzer was using a peak detector with video screen averaging to record the average signal strength at the measurement locations. Measurements were taken in a straight line radial from the aircraft at 0, 2.5, 5, 7.5, 10, 25, 20, 30, 40, 50, 60, 80, 100 and 120 feet as measured on the ground. The location of the 0 measurement for each radial was the location directly under the transmit antenna as positioned in the aircraft. In addition, on the 767 aircraft, measurements were recorded for radial distances of -2.5, -5, -7.5, -10 feet (along the same radial). Due to the shorter height above the ground level for the 737 airplane, negative distance reading (underneath in the reverse direction) were not taken for this aircraft. The distances for each of the measurement points

[1] For Cellular the antennas were Radiall/Larsen SPDA15832 and for PCS the antennas were Radiall/Larsen SPDA171900

were measured from the point directly below the transmit antenna by either a measuring tape or wheel. Also, the receive measurement test points were marked for future reference and additional testing that was performed for the calibration measurements without the aircraft. During the testing all aircraft doors and hatches were closed.

The same spectrum analyzer that was used to establish the transmit antenna input power was used to receive the signals. Therefore any small error in the spectrum analyzer readings will appear at both ends and will cancel out. The spectrum analyzer was within its calibration period, and its accuracy was confirmed prior to and after measurements were taken. Also, all the test equipment, cables and antennas used in these tests were checked and verified for accuracy of measurement prior to and after performing these measurements. The overall accuracy of this test setup is expected to be +/- 1 dB.

Setting	Cell	PCS
Receiver Resolution Bandwidth	30 KHz	30 KHz
Video Bandwidth	30 KHz	30 KHz
Sweep Time	100 mS	100 mS
Span	1 MHz	1 MHz
Center Frequency	889.68 MHz	1969.90 MHz

Table 1 Measurement equipment settings

Table 2 and Figure 1 below identify the testing locations in the 767-200 and Table 3 and Figure 2 below identify the testing locations in the 737-200 aircraft. Four of these points were made at window seats, with the antenna in full view of the window and at approximately 4 inches from the cabin window (See Figure 7 below as an example). This location presents the worst case scenario for a mobile unit and it has a high probability of occurring for a passenger sitting at a window seat with a mobile phone facing the outside of the aircraft. Additionally, V-COMM tested two interior positions (front and rear) identified as pico-cell antenna locations and one aisle seat position in each aircraft.

For this report, all distances referenced represent the horizontal separation distance from the transmit antenna inside the airplane cabin to the receive antenna outside the cabin along the specified radial. In addition, the incident angle of the signal path is computed and shown in this report, using the heights of the antennas above ground and the horizontal separation distances of the antennas. The receive antenna outside the aircraft was positioned vertically 5 feet above the ground, and the height of the transmit antennas were referenced to the transmit location with the aircraft (i.e. the transmit antenna at the 767 aircraft window was about 16.5 feet above the ground, and for the 737 aircraft was about 11.7 feet above the ground). These incident angles are show from the horizon angle (0 degrees) to the 90 degree vertical angle representing directly underneath the plane (pointing straight down).

Although the testing area was clear of any nearby reflecting structures, it is known that both pavement and earth can produce reflections that can affect the readings obtained. For these reasons, V-COMM performed “calibration” runs for each of the measurement points along the radials after the aircraft testing was completed for both bands and aircraft. For the calibration runs, the aircraft was removed from the testing area for these tests. The transmit antennas were located at the exact same locations and heights above the ground level as they were used in the aircraft measurements (see figures Figure 10 and Figure 17 below), using the exact same receive antennas and stand, and the same transmit and receive equipment that was used as in the testing with the aircraft. Then, the same radial measurements were conducted for both Cellular and PCS measurements, in the same locations. With this measurement approach, we can show the airplane leakage result in this report as the difference in received signal strength between the measurements with the aircraft, and the same calibration measurement without the aircraft present. This delta approach to measurement nulls out the effect of any ground reflections that may exist in the environment, since the comparison is between two actual empirical results performed in the same physical environment.

The results that are given in the tables of this report are in terms of the average leakage values for the measurement points along radials having incident angles between the horizon and approximately 40 degrees below the horizon. This approximately corresponds to the measurement points where the transmit antenna at the window seats come into view (line-of-sight) with the receive antenna outside the aircraft. For the 767 this was at the 15 foot measurement point (horizontal separation distance) from the reference. For the 737 this was at the 10 foot measurement point. Therefore, the results given in the tables in this report represent the average of ten or more readings along a radial. Therefore, these *averaged* values represent the results with increased statistical significance over a single measurement point on the radial.

In addition, it should be noted that this same range of incident angles also correspond to the worst case (least path loss) incident angles for typical Cellular and PCS base station antenna patterns.

Below the 40 degree angle (below the horizon), the signal path is attenuated considerably by the aircraft cabin, and also will be attenuated by the nulls in the antenna patterns of typical terrestrial base stations. Therefore, the results for the vertical angles below 40 degrees are not included in the average results reported in the tables in this report.

For this study and report, the positive number results indicate measurements above (signal strength increase or gain) and negative numbers indicate measurements lower than (signal loss) the reference calibration measurements (without the aircraft). Therefore, these measurements represent the airplane leakage (or the signal path gain or loss) for each incident angle and azimuth provided in this report through the airplane cabin.

The detailed measurement data for all measurements along the radials performed in the study, for all antenna positions, aircraft, frequencies, azimuths and incident angles are given in section 7.1 of this report.

Test Point	Seat Location	Test	Band	Direction
1	30 G, Window	A Up	Cell	Broadside Shade Up
		A Down	Cell	Broadside Shade Down
		B UP	PCS	Broadside Shade Up
		B Down	PCS	Broadside Shade Down
		C	PCS	25 Deg Aft
		D	Cell	25 Deg Aft
		E	Cell	45 Deg Aft
		F	PCS	45 Deg Aft
		G	PCS	25 Deg Fore
		H	Cell	25 Deg Fore
		I	PCS	45 Deg Fore
		J	Cell	45 Deg Fore
		K	PCS	Circle
		L	Cell	Circle
2	5F, Window	A	Cell	Broadside
		B	PCS	Broadside
3	Pico, Front	A	PCS	Broadside
		B	PCS	35 Deg Aft
		C	PCS	35 Deg Fore
		D	Cell	Broadside
		E	Cell	35 Deg Aft
		F	Cell	35 Deg Fore
4	Pico, Back	A	Cell	Broadside
		B	PCS	Broadside
5	5D, Aisle	A	PCS	Broadside
		B	Cell	Broadside

Table 2, 767-200 Testing Locations

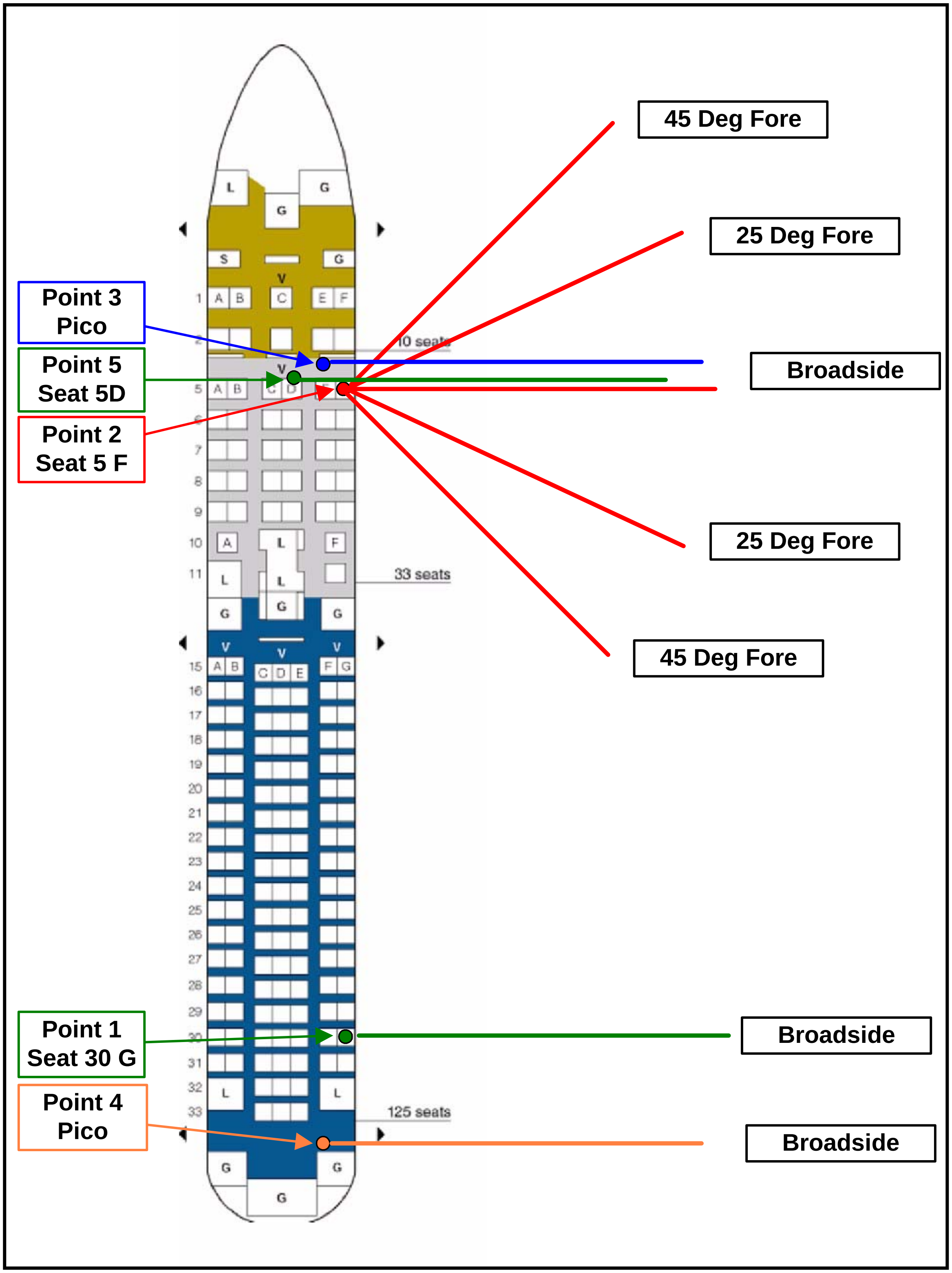

Figure 1, 767-200 Seating Chart and Test Point Locations

Test Point	Seat Location	Run	Band	Direction
6	20 F, Window	A	Cell	Broadside
		B	PCS	Broadside
7	4F, Window	A	PCS	Broadside
		B	Cell	Broadside
		C	Cell	30 Deg Fore
		D	Cell	60 Deg Fore
		E	Cell	30 Deg Aft
		F	Cell	60 Deg Aft
		G	PCS	30 Deg Fore
		H	PCS	60 Deg Fore
		I	PCs	30 Deg Aft
		J	PCS	60 Deg Aft
8	4D, Aisle	A	PCS	Broadside
		B	Cell	Broadside
9	Pico, Front	A	Cell	Broadside
		B	PCS	Broadside
10	Pico, Back	A	PCS	Broadside
		B	Cell	Broadside

Table 3, 737-200 Testing Locations

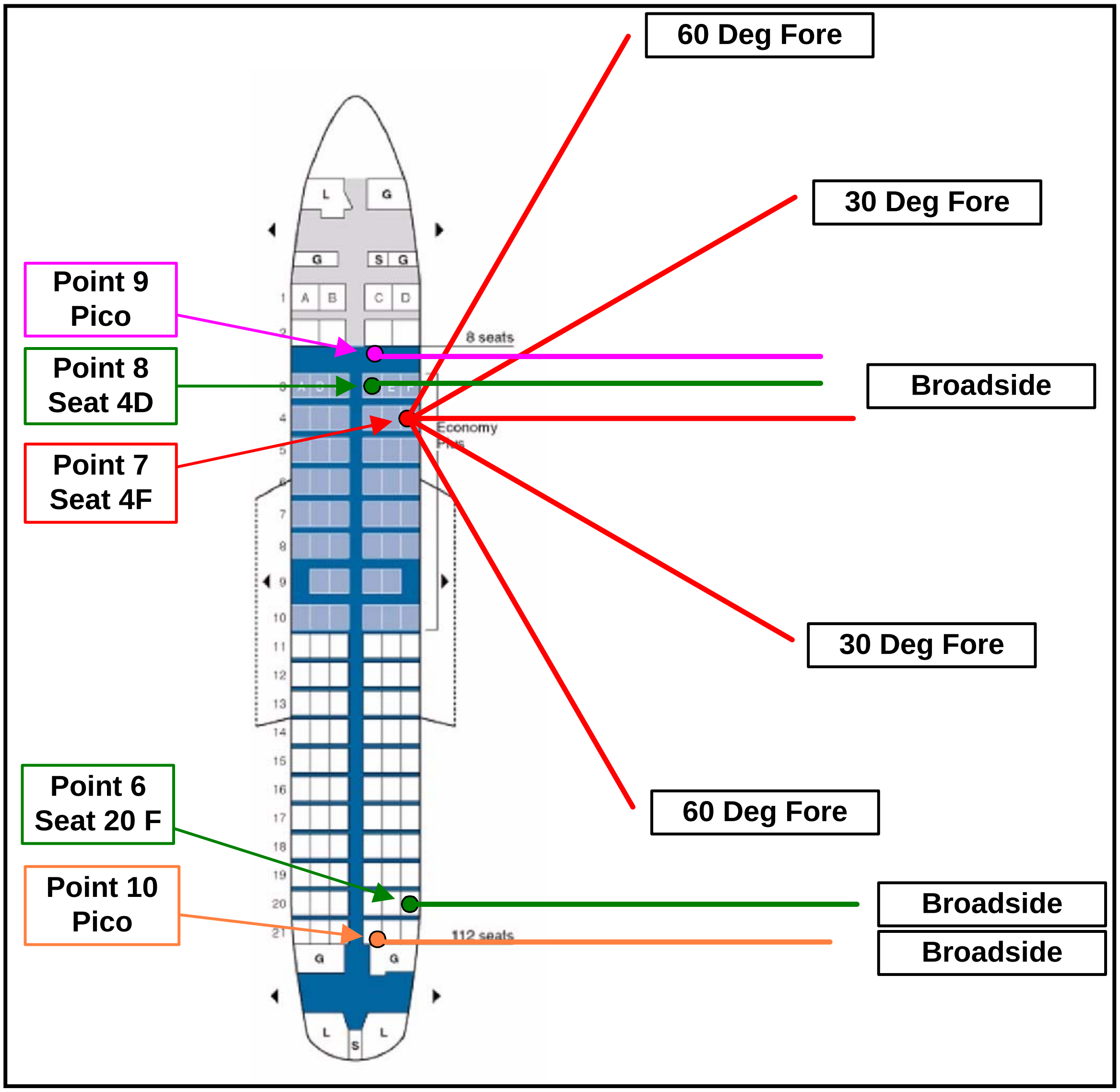

Figure 2, 737-200 Seating Chart and Testing Locations

3.2. Pictures and Diagrams of Test Setup

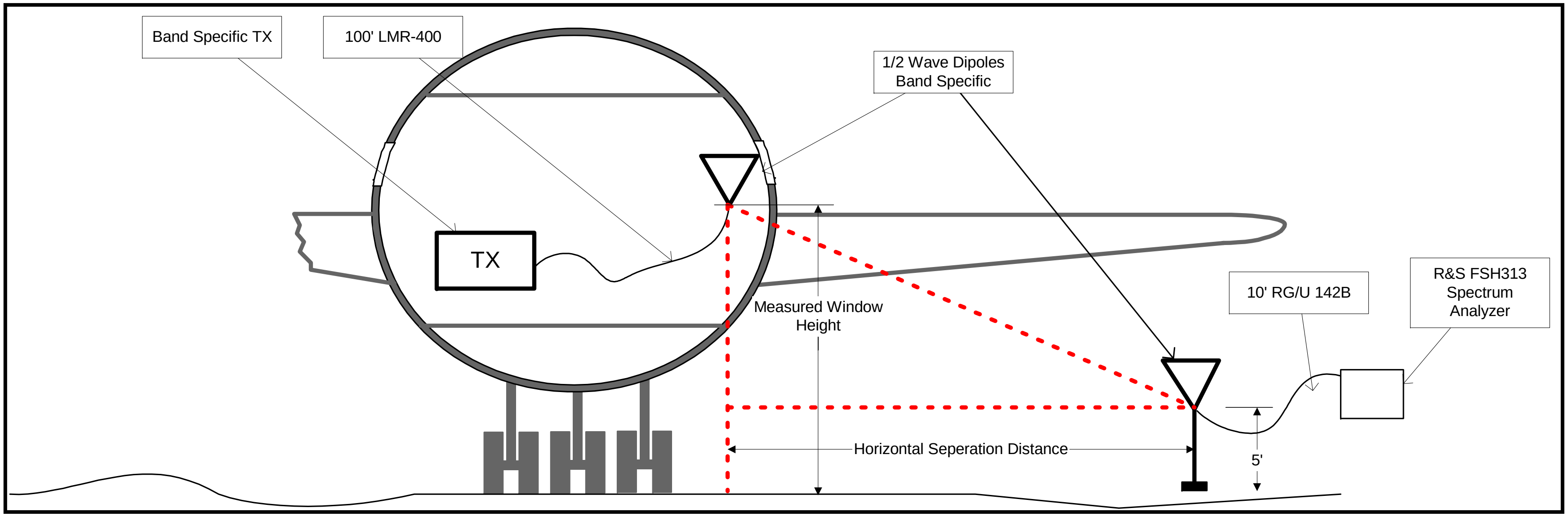

Figure 3, Testing Setup

Figure 4, Test Transmitter

Figure 6, Boeing 767, Testing Side

Figure 5, Typical Receive Test Location

Figure 7, 767 Test Point 1, Window Seat 30 G

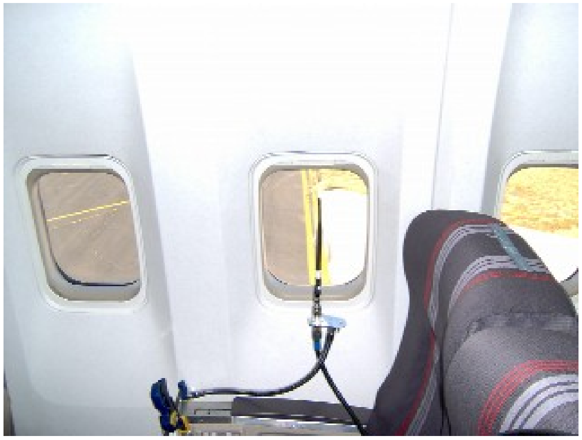

Figure 8, 767 Test Point 2, Window Seat 5F

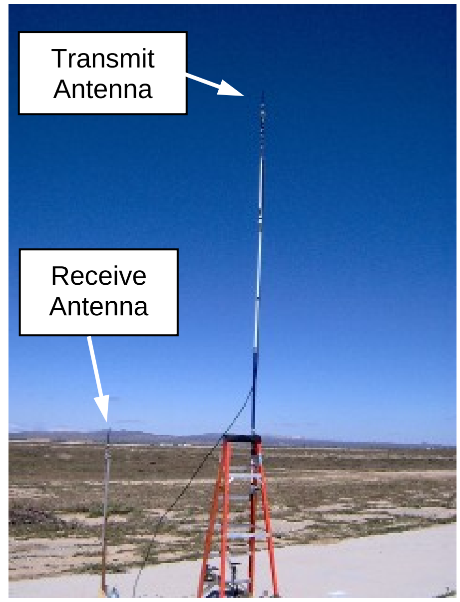

Figure 10, 767 Calibration test (without aircraft)

Figure 9, 767 Test Point 4, Pico-cell Antenna Placement (front of cabin)

Figure 11, Transmit and Receive Antenna (Cellular) -- PCS uses similar setup

Figure 12, Boeing 737 Testing Side

Figure 13 737 Point 6, Window Seat (Seat 20D)

Figure 14, 737 Point 7, Window Seat (Seat 4F)

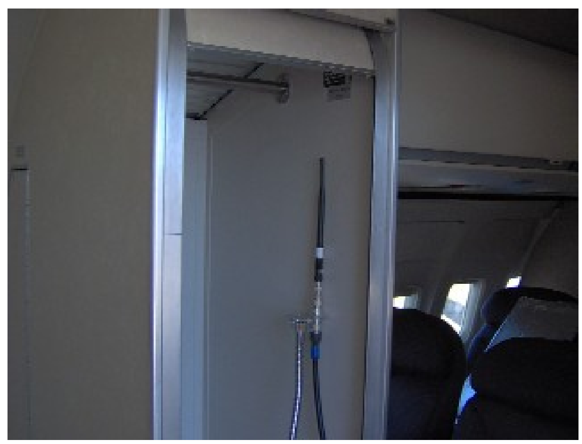

Figure 15, 737 Point 9 Front Pico-Cell

Figure 16, 737 Point 10 Rear Pico-Cell

Figure 17, 737 Calibration test (without aircraft)

4. Test Results and Findings

4.1. Leakage, Broadside Azimuth, from Window Seat

For the measurements performed at the window seats, the transmit antenna was placed at the window seat at approximately 4 inches from the aircraft window, and centered horizontally within the window. The top of the antenna was the same level of the top of the window. This position would represent the likely case position for a passenger holding a handset adjacent to the window when sitting at a window seat of the aircraft. For these measurements, the radial measurement points were perpendicular (broadside azimuth) to the aircraft with the antenna in view of the window. Two window seat locations were included in the study for each aircraft, at the front and back of the aircraft for comparison.

As expected, the broadside window seat results showed the highest leakage of signal, or strongest signal strength, outside the airplane cabin for all the tests performed in this study. The results of these tests (Locations 1A, 1B, 2A, 2B, 6A, 6B, 7A, 7B) are summarized below in Table 4, with the average airplane cabin leakage results show in the table in dB. The positive values represent a signal path gain (leakage), negative values represents a signal path loss through the airplane cabin window as compared to the signal received with no aircraft present (as measured in the calibration runs without the aircraft at the same measurement locations).

Airplane	Window Seat Location	Cell	PCS
767	1	0.3	-0.8
	2	1.9	-1.2
	Average	**1.1**	**-1.0**
737	6	2.8	5.6
	7	2.6	2.9
	Average	**2.7**	**4.3**

Table 4, Window Seat Airplane Leakage Results, Broadside Azimuth (in dB)

For the 767 airplane, although there is a slight gain in the Cellular band and slight loss in the PCS band, indicating that the results are within our margin of measurement error, and there is little change (i.e. approximately 1 dB gain for Cellular, 1 dB loss for PCS) imparted by the aircraft window to the signal strength of an antenna in full view of the window. Therefore, for the 767 airplane the broadside azimuth represents approximately no effect (~0 dB loss) in leakage through the aircraft window, for both the Cellular and PCS frequency bands.

However, for the 737 airplane, a leakage *gain* (increase in signal strength) was observed through the cabin window of the airplane on the order of 3 dB on average for Cellular, and 4 dB on average for PCS. This effect, an increase is signal path through an opening, is analyzed further in section 5.3 of this report.

4.2. The Influence of a Window Shade

In this test, on the 767 at Point 1, a radial was run for both Cellular and PCS. At each measurement point, two readings were made, one with the window shade up and one with the shade down that was directly in front of the transmit antenna at a window seat. Given our margin of measurement error, the window shade's influences on the signal path leakage is minimal to non-existent.

Window Shade Position	Cell	PCS
Up	0.3	-0.8
Down	0.0	-1.0
Delta	**-0.3**	**-0.2**

Table 5, Leakage Effects of a Window Shade (in dB)

4.3. Partially Blocked Azimuths

At one window seat location for each airplane (point 1 on the 767 and point 7 on the 737), 4 non-perpendicular radials were run to observe the effect on the signal leakage. The transmit antenna was again placed about 4 inches from and centered horizontally in the window. The results are given in Table 6 below and graphed in Figure 35 of the Appendix as the average of the radial measurements. The results, as expected, indicate that as the azimuth changes from perpendicular to the aircraft, the signal leakage will decreases considerably (a reduction in signal strength, or increase in penetration loss) and proportionately for azimuths off the perpendicular (broadside azimuth from airplane).

The test results for the 737 airplane at the 30 degree azimuths show a decrease in signal strength outside the aircraft of 5.3 and 11.1 dB, on average for the Cellular and PCS bands, respectively, below the broadside azimuth of the aircraft (broadside reference is shown at 0 degree azimuth in the table below). For the 767 airplane, the 25 degree azimuths show a decrease in signal strength outside the aircraft of 1.6 and 5.4 dB, on average for the cellular and PCS bands, respectively, below the broadside azimuth of the aircraft. Therefore, the average attenuation for the 25 and 30 degree azimuths are 3.5 and 8.3 dB, for the Cellular and PCS frequency bands respectively.

The test results for the 737 airplane at the 60 degree azimuths show a decrease in signal strength outside the aircraft of 13.5 and 13.2 dB for the Cellular and PCS bands, respectively, below the broadside azimuth of the aircraft. For the 767 airplane, the 45 degree azimuths show a decrease in signal strength outside the aircraft of between 8.2 and 10.1 dB, for the Cellular and PCS bands, respectively, below the broadside azimuth of the aircraft. Using the broadside measurements as the reference, the average attenuation for the 45 and 60 degree azimuths are 10.8 and 11.7 dB, for the Cellular and PCS frequency bands respectively. Overall, the results indicate that for partially block angles (between 25 and 60 degree azimuths), the Cellular band had showed a 7.1 dB decrease and PCS band a 10.0 dB decrease in signal leakage, as compared to the broadside measurements.

Azimuth (degrees)	Cell 767	PCS 767	Cell 737	PCS 737
Aft -60			-7.1	-7
-45	-7.4	-7.4		
30			-0.9	-6.7
-25	-0.4	-7.9		
0	0.3	-0.8	2.8	5.6
25	-2.3	-4.5		
30			-4.1	-4.4
45	-8.3	-14.5		
Fore 60			-14.4	-8.3

Table 6, Azimuth Effects on Leakage (in dB)

4.4. 360 Degree Test

This test was conducted on the 767 airplane at Point 1 (a window seat). Measurements were recorded at every 30 degrees along a circular path with a radius of 25 feet (horizontal separation distance). The results are graphed below in Figure 18 (Cellular) and Figure 19 (PCS) below. As is expected, significant attenuation of the leakage is experienced for azimuths away from the full broadside view. However, in the case of the PCS antenna, there is a substantial “back lobe” leakage at a level of 10 dB or lower than compared to the broadside measurement, from the windows on the opposite side of the airplane at PCS frequencies. The sharp null at 120 degrees for the PCS test was due to blockage from aircraft’s wing.

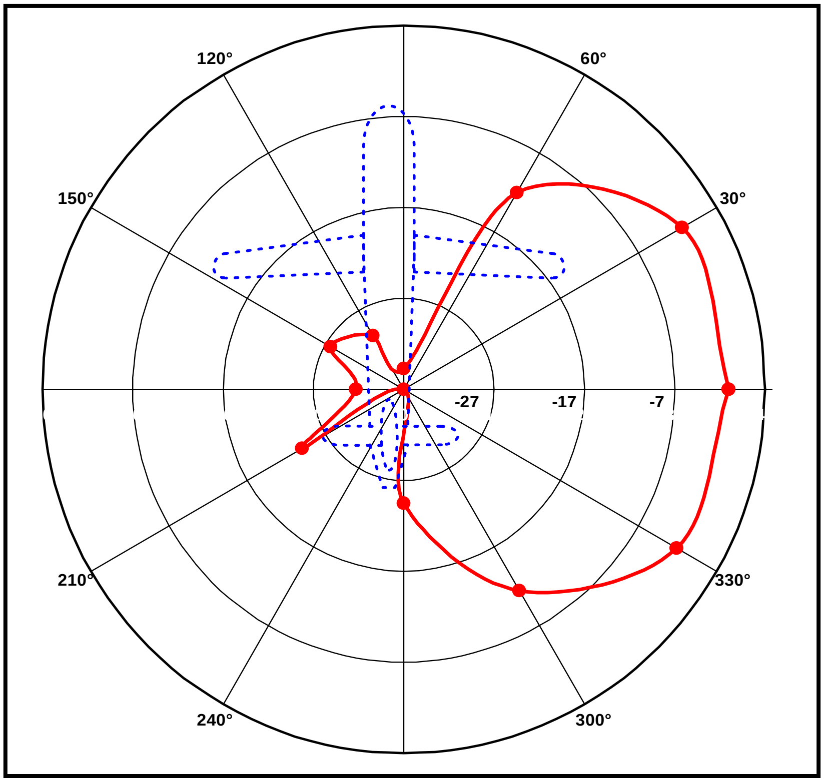

Figure 18, Cellular Leakage, 360 Degrees

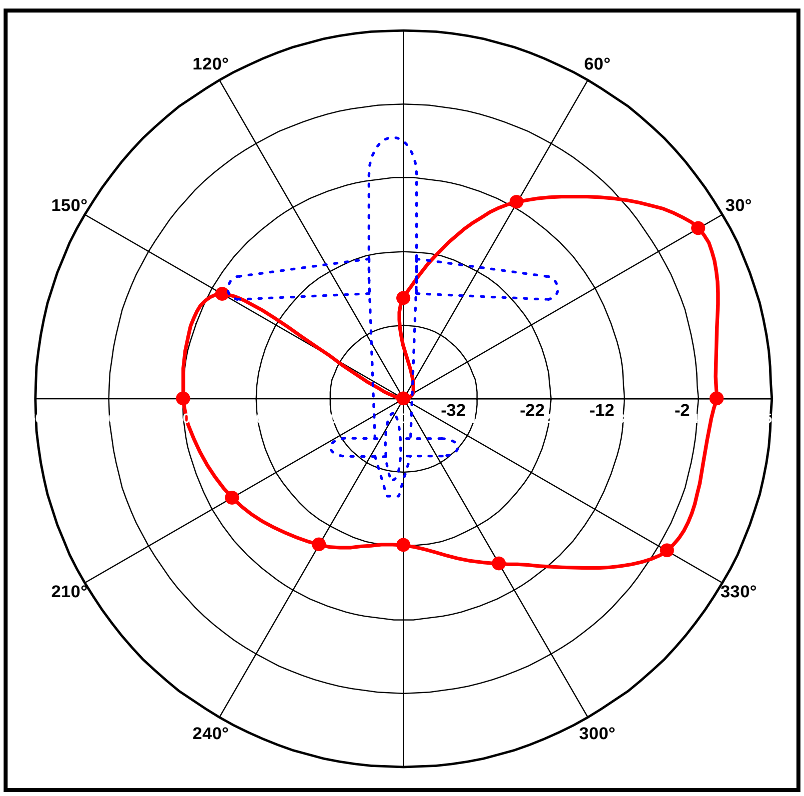

Figure 19, PCS Leakage, 360 Degrees

4.5. Aisle Seating Tests

The signal leakage tests were performed at one aisle seating position in each aircraft, point 5 in the 767 and point 8 in the 737. The average signal leakage results are provided in Table 7 below and graphed in Figure 27 (767) and Figure 28 (737) in the Appendix. As is expected, the results show a considerable attenuation of the leakage from these locations which do not have a substantial view from the aircraft window, as compared to the window seating areas. The results averaged along the radial for the aisle seating Cellular tests indicate a range from 7 to 10 dB (8.4 dB on average), and for PCS tests range from 10 to 12 dB of signal loss through the airplane cabin (10.8 dB on average) for the incident angles between the horizon and 40 degrees below the horizon.

Airplane	Aisle Seat Location	Cell	PCS
767	5	-9.9	-11.9
737	8	-6.9	-9.8

Table 7, Aisle Seat Leakage Results (in dB)

Therefore, for the aisle seat locations, the signal strength decreased through airplane cabin by an average of 8 dB for the Cellular band and 11 dB for PCS band, when considering angles of the horizon to 40 degrees below.

When considering the vertical angles of 10 to 30 degrees below the horizon (which are the worst case incident angles for typical base station antenna patterns), the signal from the aisle seating location was attenuated by the airplane cabin about 6 to 10 dB for the Cellular band, and 5 to 10 dB for the PCS band depending on the aircraft. These incident angles should be used for assessment of the interference potential of mobile phones operated at aisle seating locations because they represent the worst case incident angles toward the terrestrial networks, and also coincide with the worst case incident angles of typical terrestrial base station antenna patterns.

4.6. Pico-Cell Antenna Test Locations

For these tests, a front and back pico-cell antenna location was used in each aircraft (767 point 3 in front, point 4 in back and 737 point 9 in front, point 10 in back). The measurements along the radials were recorded for these pico-cell antenna locations, and the results are provided in Table 8 below and graphed in Figure 29 (767) and Figure 30 (737) in the Appendix. As expected and consistent with the aisle seating radial measurements, the pico-cell antenna locations show there is considerable attenuation of the leakage through the airplane cabin from these locations.

Airplane	Location	Measurement	Cell	PCS
767	Point 3, Front	Broadside	-10.9	-10.8
		35 Deg Aft	-15.2	-10.3
		35 Deg Fore	-12.9	-11.1
	Point 4, Back	Broadside	-18.5	-10.9
	Average		**-14.4**	**-10.8**
737	Point 9, Front	Broadside	-14.4	-17.6
	Point 10, Back	Broadside	-19.3	-20.2
	Average		**-16.9**	**-18.9**

Table 8, Pico-Cell Antenna Leakage (in dB)

The results for the pico-cell antenna locations for the 767 airplane, for the incident angles of the horizon to 40 degrees below the horizon, show a decrease in signal strength on average outside the aircraft in the range of 11 to 19 dB for the Cellular band (or 14 dB loss on average), and in the range of 10 to 11 dB for the PCS band (or about 10 dB loss). For the 737 airplane, the pico-cell averaged results show a decrease in signal strength on average outside the aircraft in the range of 14 to 19 dB for the Cellular band (an average of 17 dB loss), and in the range of 18 to 20 dB for the PCS band (an average of 19 dB loss). For both aircraft, the average leakage results for all measurement radials for the pico cell antenna locations are 15.2 dB loss on average for the Cellular band, and 13.5 dB loss on average for the PCS band.

Therefore, for the pico cell antenna locations studied, the signal strength decreased through airplane cabin by an average 15 dB for the Cellular band and 14 dB for PCS band, when considering angles of the horizon to 40 degrees below.

When considering the vertical angles of 10 to 30 degrees below the horizon, the signal from the pico cell location was attenuated by the airplane cabin about 8 dB for the Cellular band, and 6 to 10 dB for the PCS band depending on the aircraft. These incident angles should be used for assessment of the interference potential of onboard pico cell operations because they represent the worst case incident angles toward the terrestrial networks, and also coincide with the worst case incident angles of typical terrestrial base station antenna patterns.

5. Analysis

5.1. Effects of Elevation Angles on Cabin Leakage

As reported in result tables in the previous sections of this report, the data values used were an average of the measurement points along the radial for the cases with the receive antenna in clear view (and within line-of-sight or LOS) of the transmit antenna in the cabin window. To analyze the leakage results for all incident angles or elevations the charts in the Section 7.1 of this report are provided. Two of these charts are reproduced below, Figure 20 for the 767 and Figure 21 for the 737, to show the view point or line-of-site (LOS) incident angle in which the antenna in the cabin window comes into view of the outside antenna.

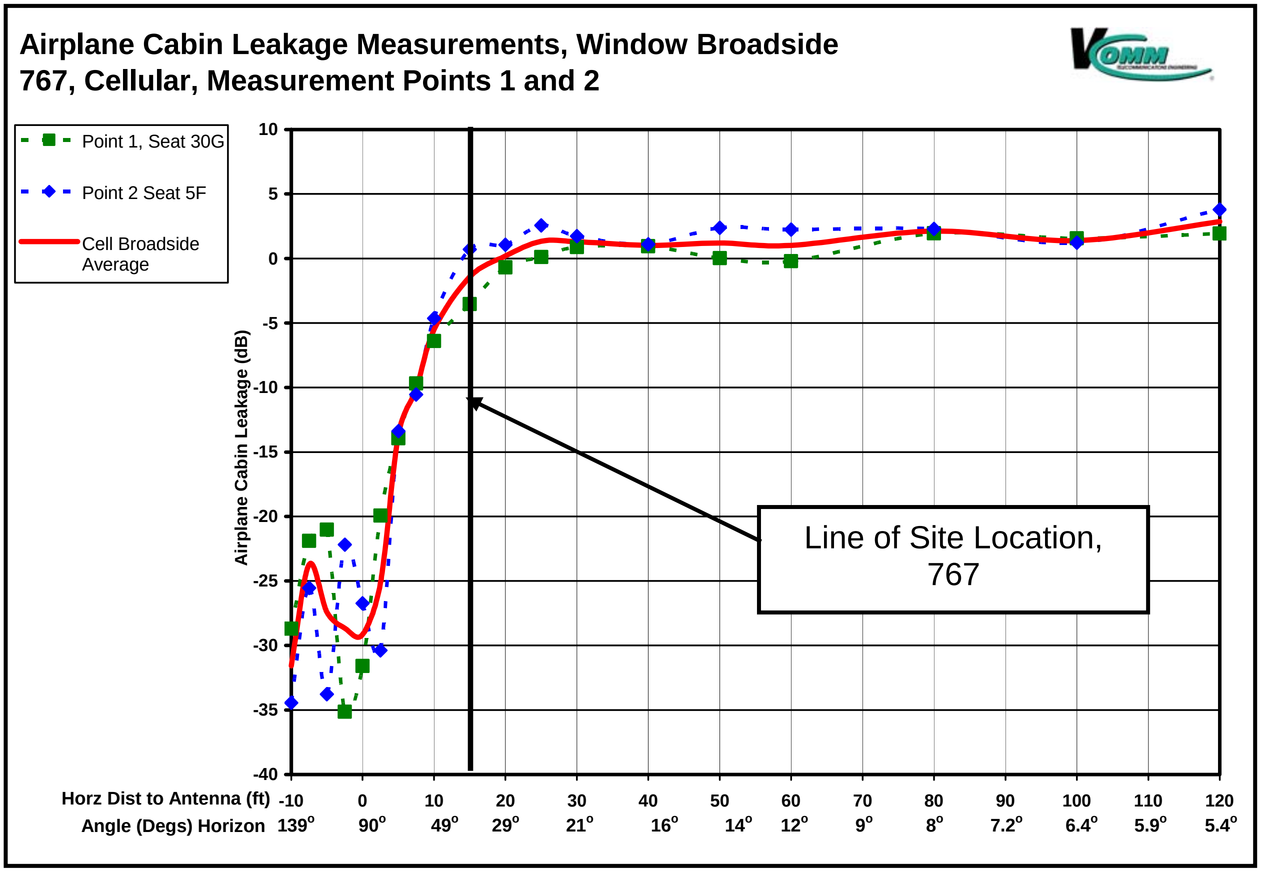

Figure 20, Point of LOS for 767 Measurements

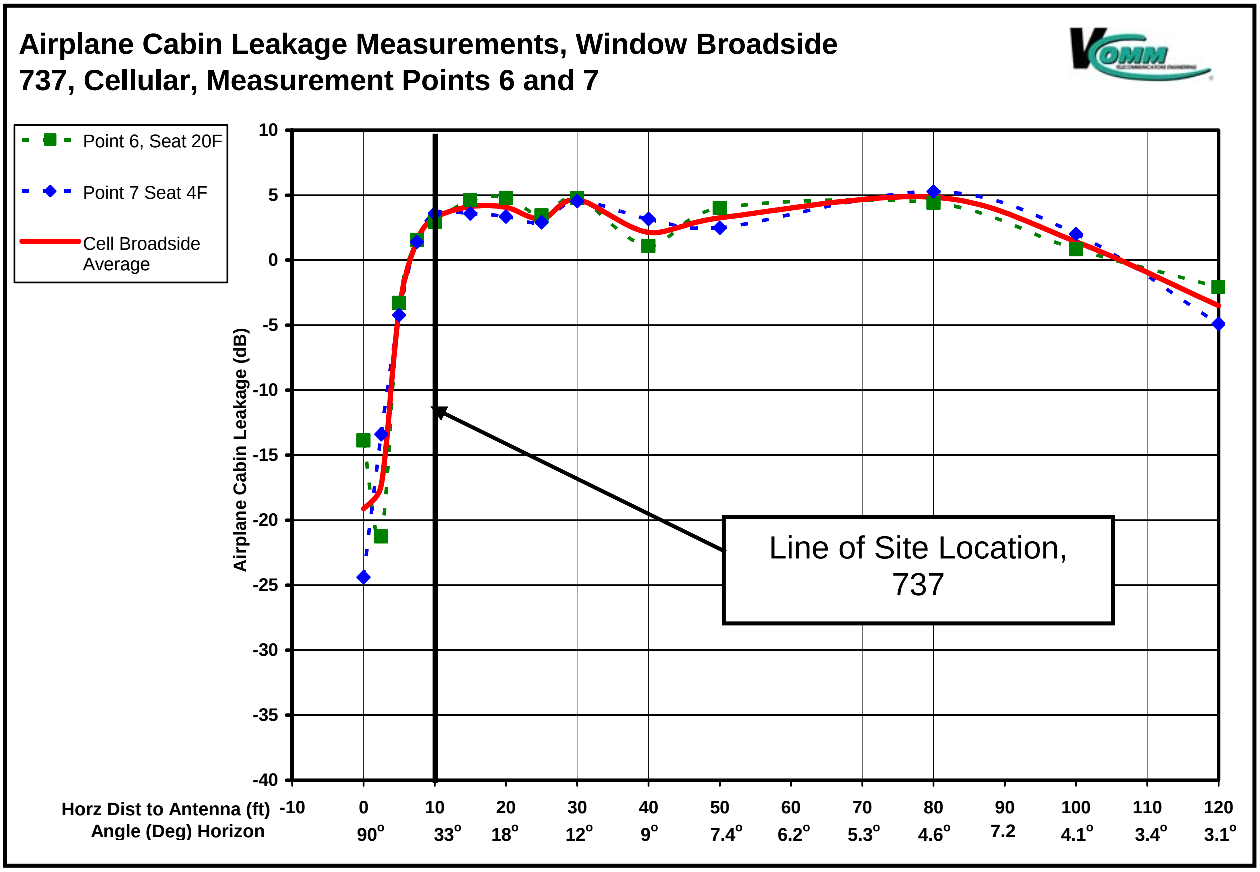

Figure 21, Point of LOS for 737 Measurements

As indicated in these graphs, that there is a Line of Site (LOS) condition existing from approximately 33 to 40 degrees for two aircraft. (For the 767 aircraft the angle is closer to 40 degrees, and for the 737 its closer to 33 degrees). These correspond to the distances that the receive antenna was in full site of the transmit antenna. Below these incident angles (i.e. greater than 40 degrees below the horizon) there is significantly less leakage through the aircraft fuselage, as expected. For both aircraft, leakage directly below the aircraft is decreased by at least 15 to 20 dB, as compared to the line of site conditions (with no loss) through the airplane cabin windows.

5.2. Worst Case Antenna Positions for Impact to Terrestrial Networks

The results of this study indicate that the worst case mobile handset position for impact to the terrestrial wireless networks will be handsets operated by window seat passengers. For the 767 airplane case, the leakage is unaffected (0 dB loss) though the cabin window and in the cases of the 737 a gain of 3 to 4 dB was observed.

In the cases where an increase in signal through the cabin window is observed as the signal path approaches the horizon angle, these cases are mitigated to an extent by the increased in signal path propagation distances toward these base stations along these longer incident angles.

5.3. Possible Effects Causing Gain through Airplane Windows

Due to the unexpected results of a signal path gains observed for the 737 aircraft, V-COMM researched other parties that may have performed similar measurements on commercial aircraft. As provided by an AeroMobile[2] presentation given at the RTCA[3] SC-202 meeting on April 12, 2005 in Washington DC., their results indicate similar results to our study for the same aircraft and frequency band. AeorMobile reports their results in terms of "isolation figures", rather than leakage figures as used in this report, which is the opposite reference (i.e. -5 dB isolation is the same as + 5 dB for signal leakage.).

The AeroMobile reports *isolation figures* of +2 dB for an Airbus A320, *-5 dB* for a Boeing 737-800, *-2 dB* for a Airbus A340-300, and 10 dB for an un-specified airplane, all at 1800 MHz. Also, these same results can be reported in terms of *leakage figures*, or -2 dB for an Airbus A320, +*5 dB* for a Boeing 737-800, +*2 dB* for a Airbus A340-300, and -10 dB for an un-specified airplane.

AeroMobile reports a +5 dB of signal gain (leakage) for a 737-800, which is consistent with the ranges that V-COMM measured for the PCS band of +2.9 for window seat location 7, and 5.6 dB for window seat location 6. Also, we reported an average for PCS of +4.3 dB gain in leakage for a 737-200 at PCS frequencies, which is less than 1 dB different than the AeroMobile findings. This further reinforces our findings that gain in leakage can exist, depending on the aircraft. The referenced presentation slide is reproduced in the Appendix 7.2 section of this report as Figure 36.

V-COMM speculates that the materials used for the windows, including the glazing material, number of individual glazing planes, glazing coatings and bezel material can affect the transmission through the window. For example, the bezel material in the 737 could be aluminum, providing a reflector around the antenna, but the material in the 767 a composite type of material, transparent to RF energy. Or it may be that the physical dimension and shape of the 767's window actually provides the gain that is seen in the 737, where the window operating (or aperture) in the 767 has approximately no gain or attenuation with a net effect of 0 dB. Additional investigation of the physical construction of the aircraft windows, in a controlled environment, would need to be studied to determine the exact cause of the gain affect seen for the 737 aircraft.

[2] See www.arinc.com/products/aeromobile/index.html
[3] See www.rtca.org/Default.asp

6. Conclusion

The worst case location for the signal leakage observed for the window seat locations and azimuths that were broadside to aircraft. At other azimuths that are not perpendicular (broadside) to the aircraft, and at other interior locations, the signal leakage decreases considerably.

For airborne handsets operated by passengers sitting at window seats on the 767 aircraft, the signal leakage through the airplane cabin is relatively unaffected (0 dB loss) by the airplane window. For the 737 aircraft the window presented a slight increase in signal strength (gain) on average in both bands, on the order of 3 to 4 dB. We believe that the signal gain of the 737 aircraft is due to the unique properties of the 737's window construction, the reflections inside the cabins and window structure, and the orientation of antenna in the aircraft. Given that this was not the case for the 767 aircraft, gain through the window of an aircraft will vary from aircraft model to model. Therefore, to assess the impact of airborne handsets used aboard commercial airplanes the signal path leakage for many airplane types should be studied to gain a good understanding of the respective airplane leakage properties and propagation issues. Further investigation will be needed to accurately identify the exact cause of this gain as seen in the 737 aircraft results. However, it should be noted that another firm that measured the cabin signal leakage for the 737 aircraft recorded similar results. As indicated on the presentation slide of AeroMobile (see Appendix 7.2) the 737 airplane results show an isolation of -5 dB for PCS frequencies (this is the same as the signal leakage of +5 dB, or signal path gain), which is within the range of the results observed in these V-COMM measurements for the same aircraft in the PCS band.

For the partially blocked azimuths from the window seating locations the average reduction in signal leakage for the 25 to 30 degree azimuths are 3.5 dB (Cellular) and 8.3 dB (PCS) for both aircraft, as compared to the worst case broadside azimuth. The average reduction in signal leakage for the 45 to 60 degree azimuths are 10.8 dB (Cellular) and 11.7 dB (PCS) for both aircraft, as compared to the worst case broad side azimuth. The average reduction in signal for all of these partially blocked views (between 25 to 60 degree azimuths) for both aircraft are 7.1 dB for Cellular, and 10.0 dB for PCS, as compared to the worst case broadside view.

For handsets operated by passengers sitting at aisle seating and for the pico-cell antenna locations, the signal path leakage is lower (greater isolation, or more attenuation) than the window seating areas.

For the aisle seat locations, the signal strength decreased through airplane cabin by an average of 8 dB for the Cellular band and 11 dB for PCS band, when considering angles of the horizon to 40 degrees below. When considering the incident angles of 10 to 30 degrees below the horizon (which are the worst case incident angles for typical base station antenna patterns), the signal from the aisle seat location was attenuated by the airplane cabin about 6 to 10 dB for the Cellular band, and 5 to 10 dB for the PCS band depending on the aircraft. These incident angles should be used for assessment of the interference potential of mobile phone operations because they represent the worst case incident angles toward the terrestrial networks, and also coincide with the worst case incident angles of typical terrestrial base station antenna patterns.

For the pico cell antenna locations studied, the signal strength decreased through airplane cabin by an average 15 dB for the Cellular band and 14 dB for PCS band, when considering angles of the horizon to 40 degrees below. When considering the vertical angles of 10 to 30 degrees below the horizon, the signal from the pico cell location was attenuated by the airplane cabin about 8 dB for the Cellular band, and 6 to 10 dB for the PCS band depending on the aircraft.

For interference analyses assessing the impact of airborne handset operations using cellular or PCS spectrum the worst case signal leakage (through the airplane cabin toward the terrestrial wireless networks) results should be used. As indicated in this study, the worst case signal leakage results are shown to occur at the window seat and broadside azimuths. In these cases, the approximate loss through the airplane cabin can be assumed to be approximately 0 dB for the Cellular and PCS bands, based upon the measurements for the Boeing 767 airplane. In addition, in some cases the signal will experience an increase in signal strength on the order of 3 to 4 dB, when propagating through the cabin window, as observed for the Boeing 737 airplane. For interference analysis assessing the potential interference from pico-cell transmissions in the airplane cabin, the signal path loss at least 8 dB for Cellular and 6 to 10 dB for PCS should be used.

7. Appendix

7.1. Detailed Charts of the Results

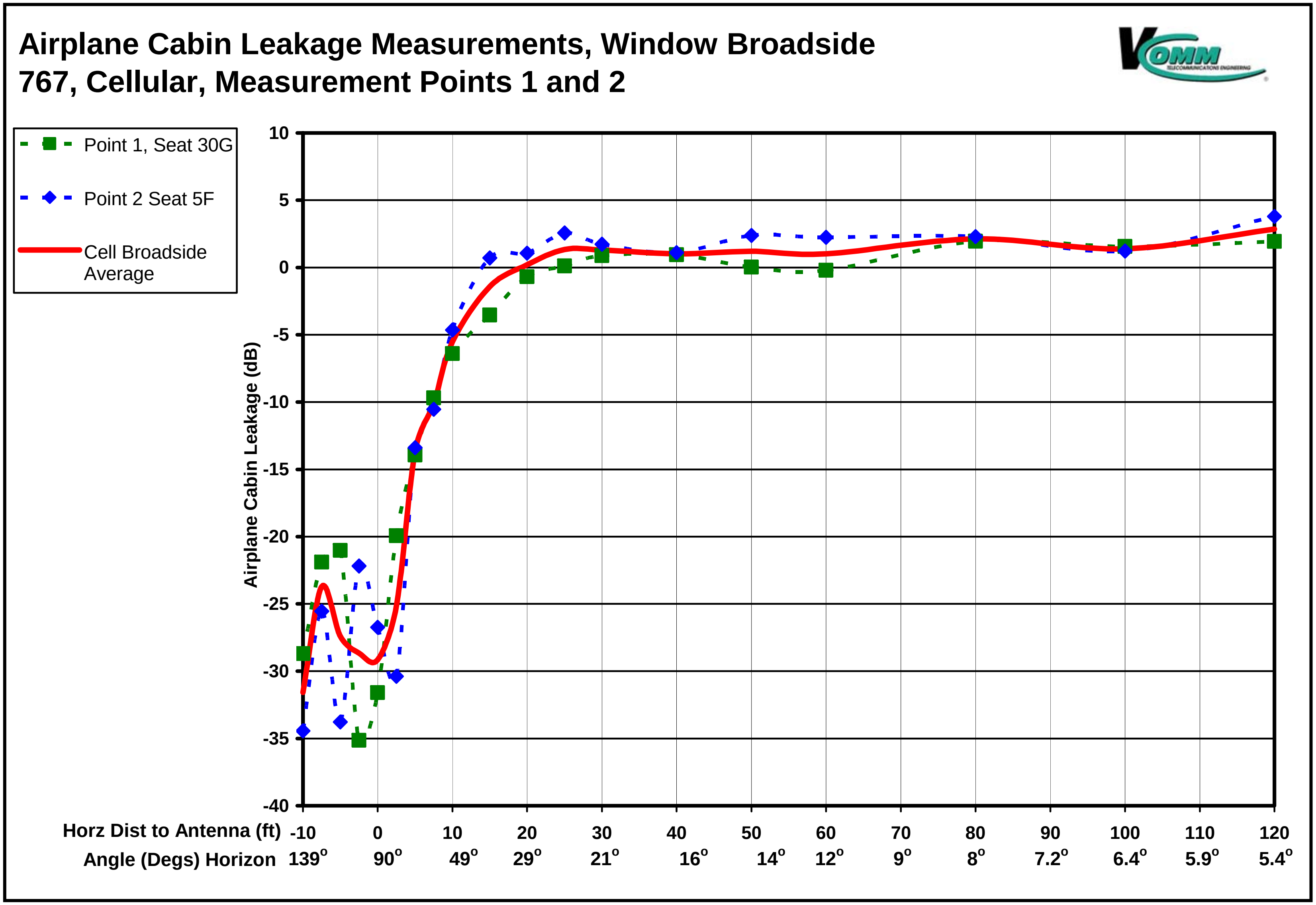

Figure 22, Window Broadside Measurements, 767 Cellular

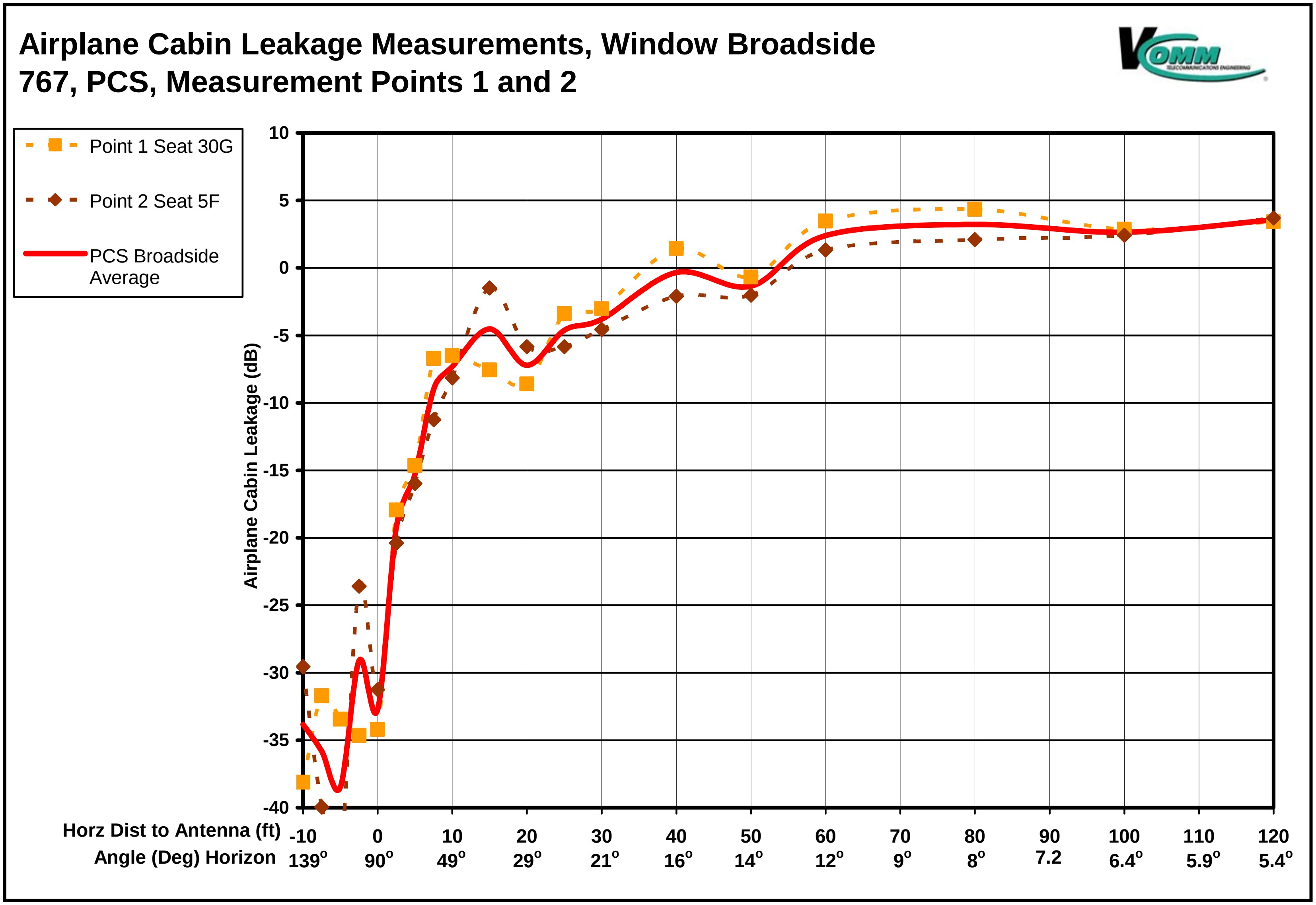

Figure 23, Window Broadside Measurements, 767 PCS

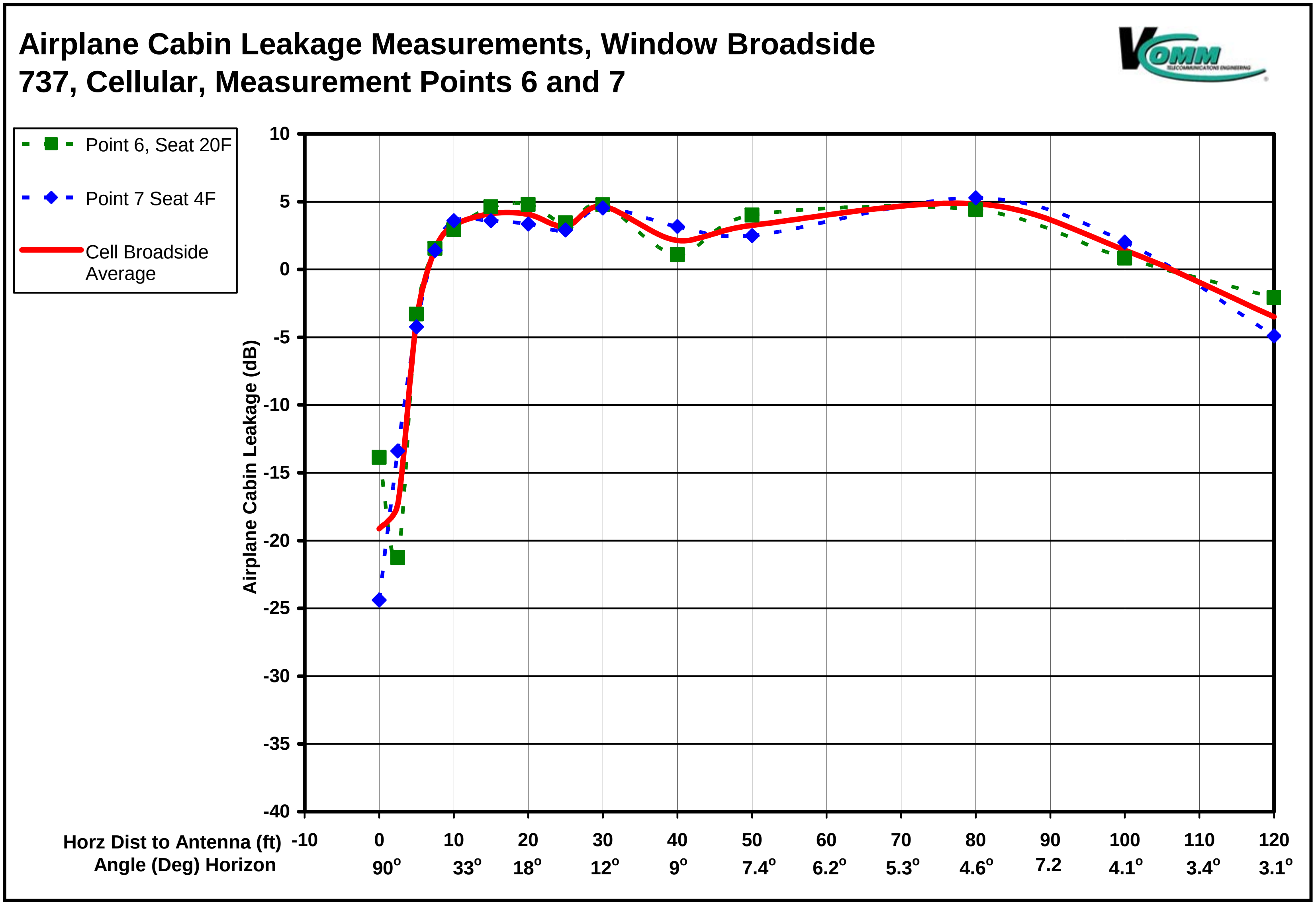

Figure 24, Window Broadside Measurements, 737 Cellular

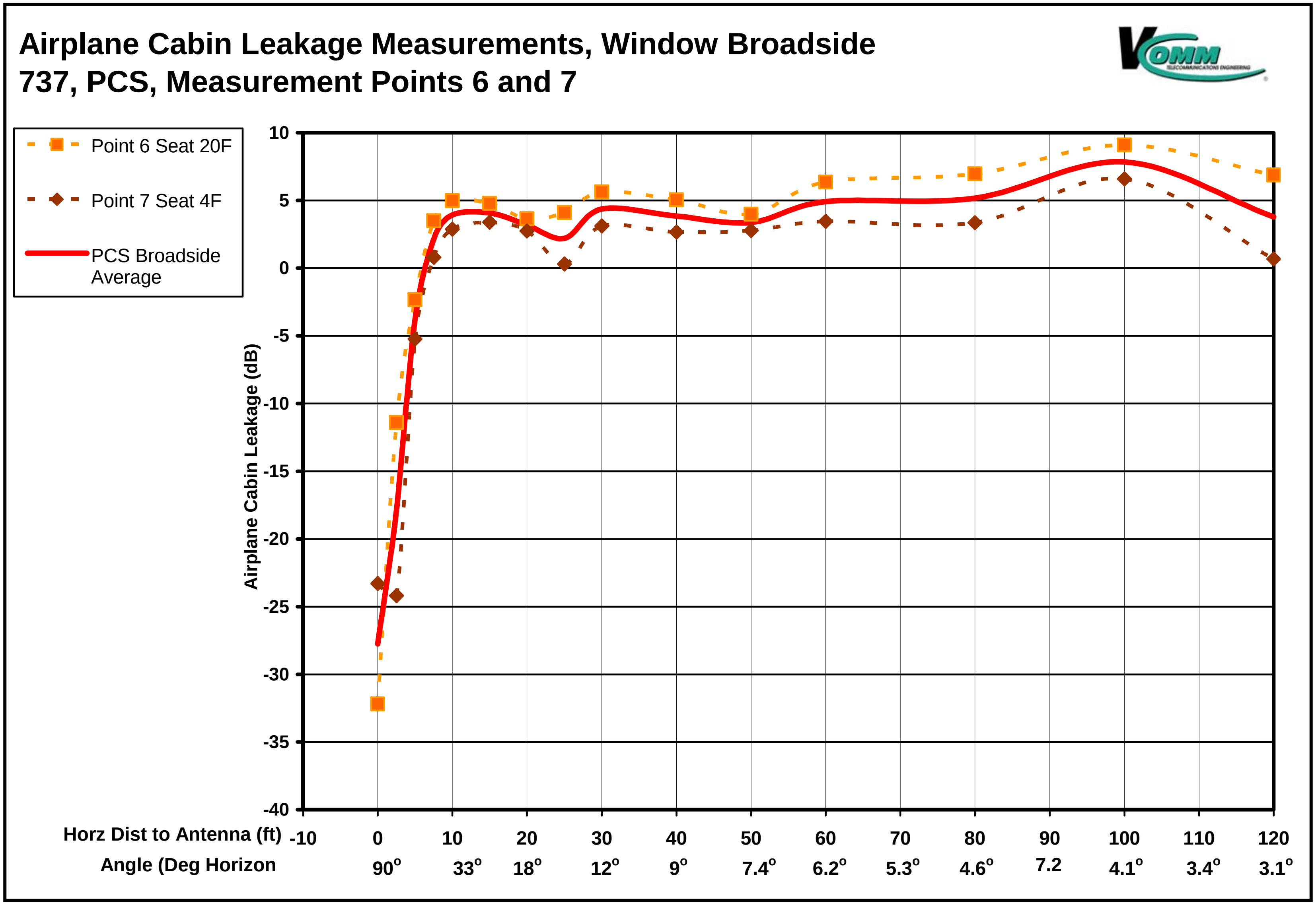

Figure 25, Window Broadside Measurements 737 PCS

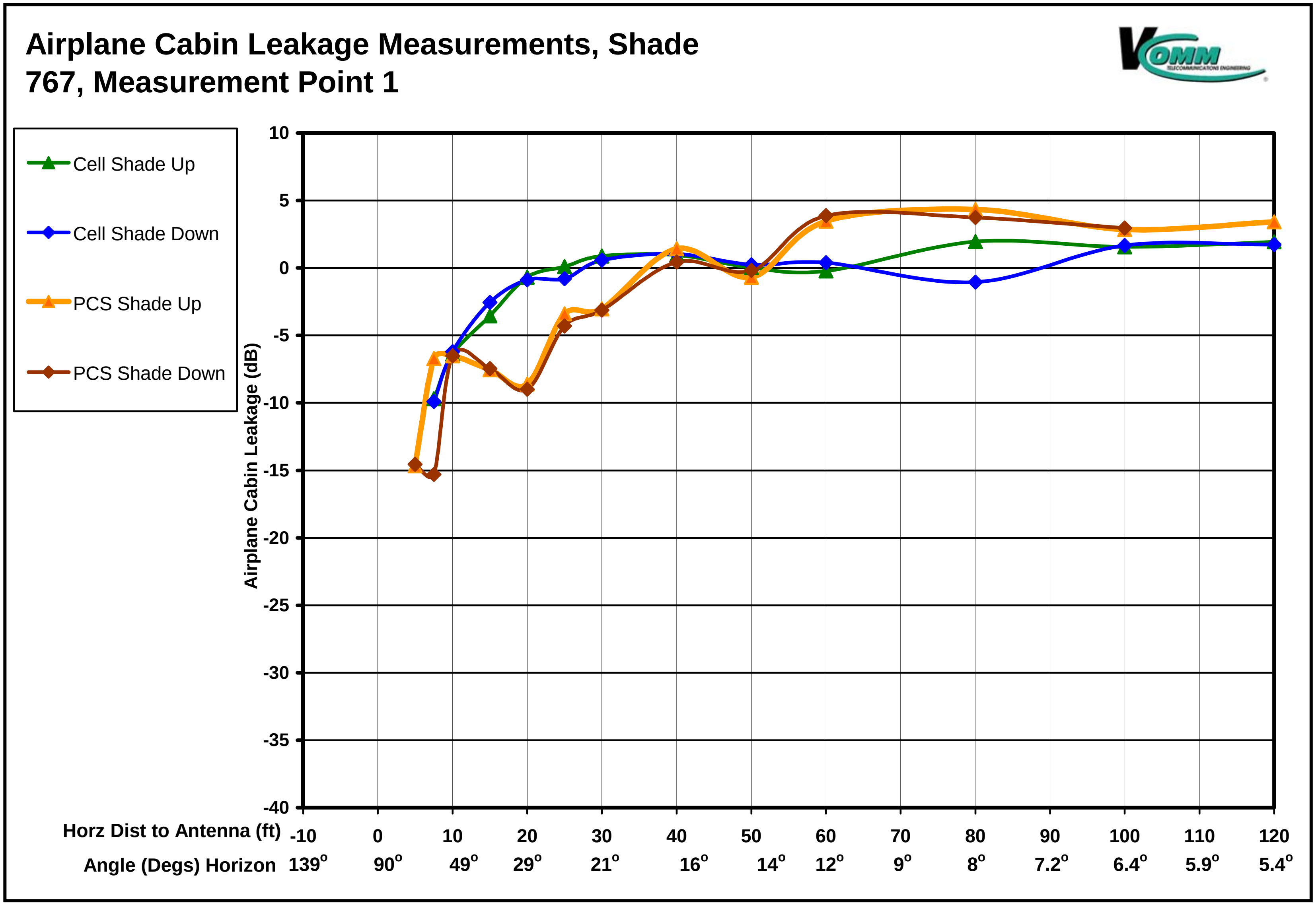

Figure 26, Window Shade Measurements, 767 Cellular and PCS

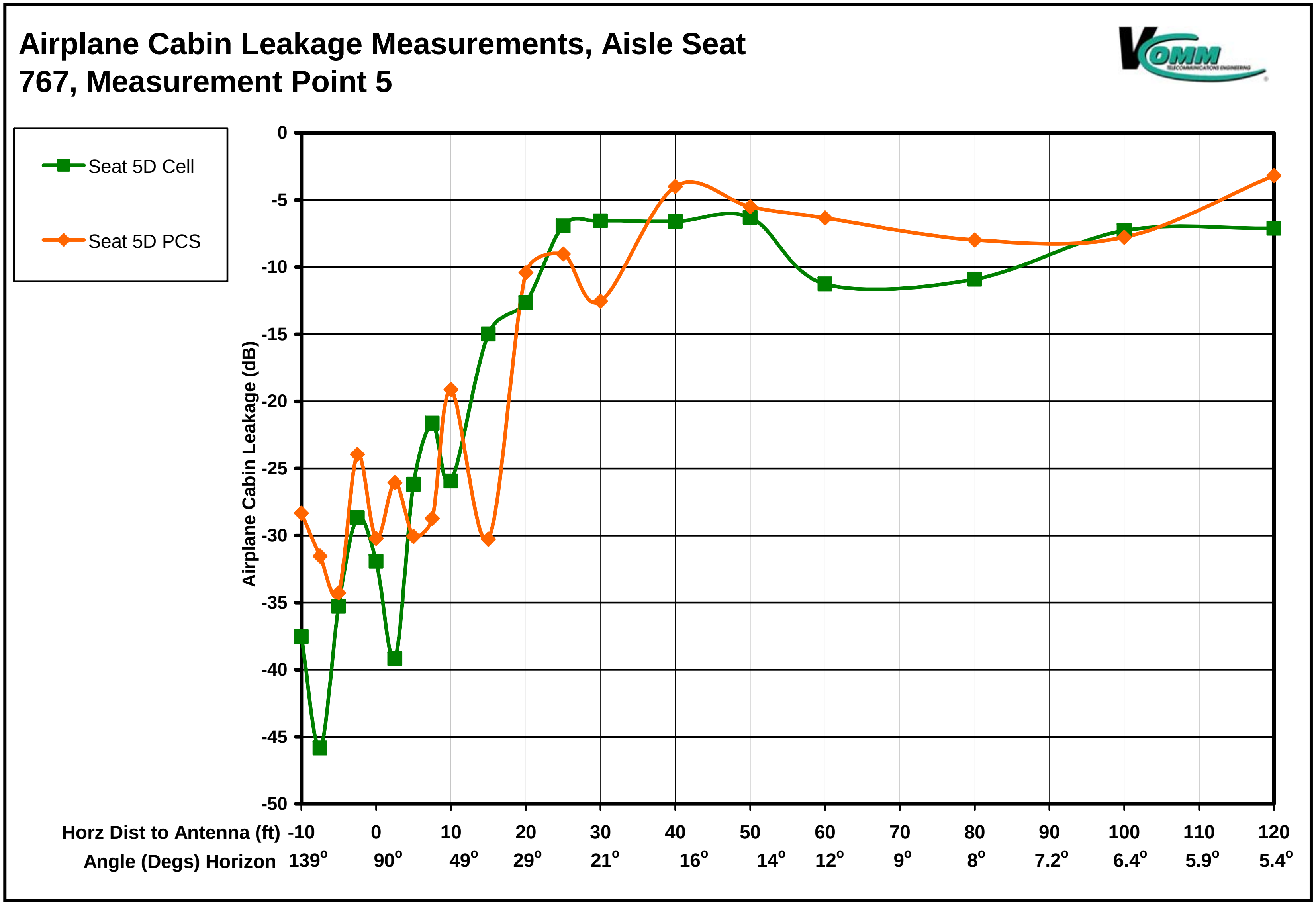

Figure 27, Aisle Seat Measurements, 767

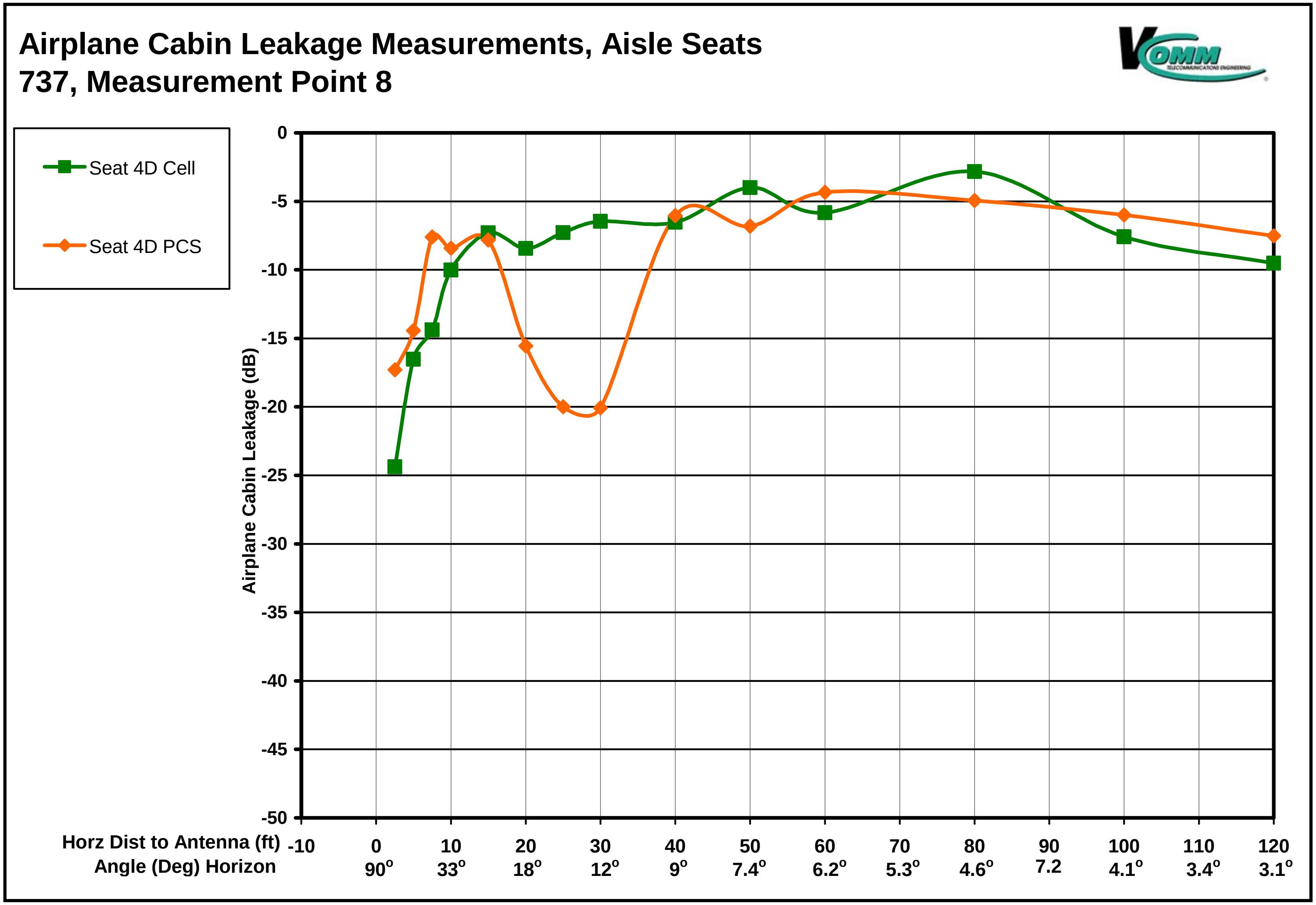

Figure 28, Aisle Seat Measurements, 737

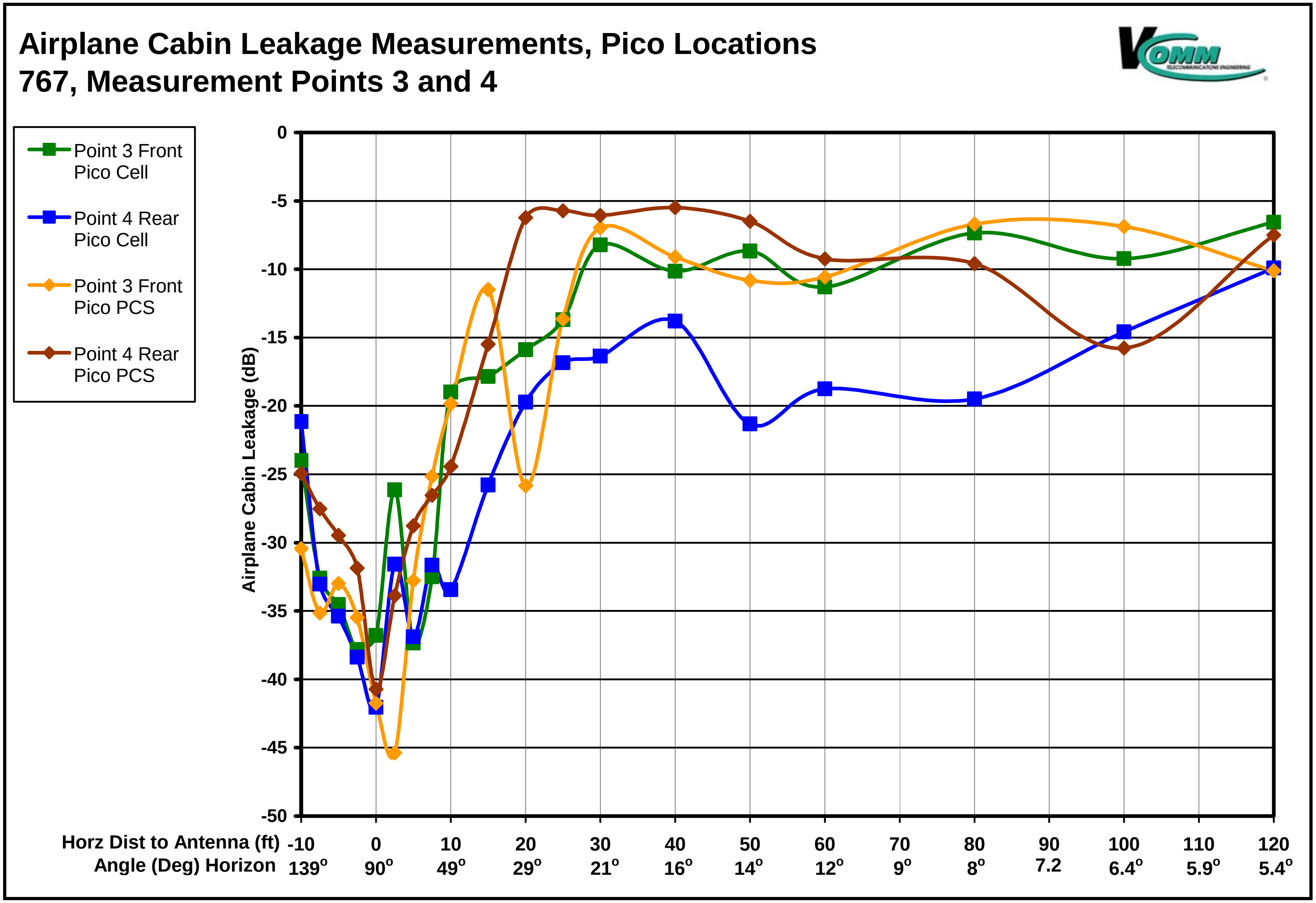

Figure 29, Pico Base Station Measurements, 767

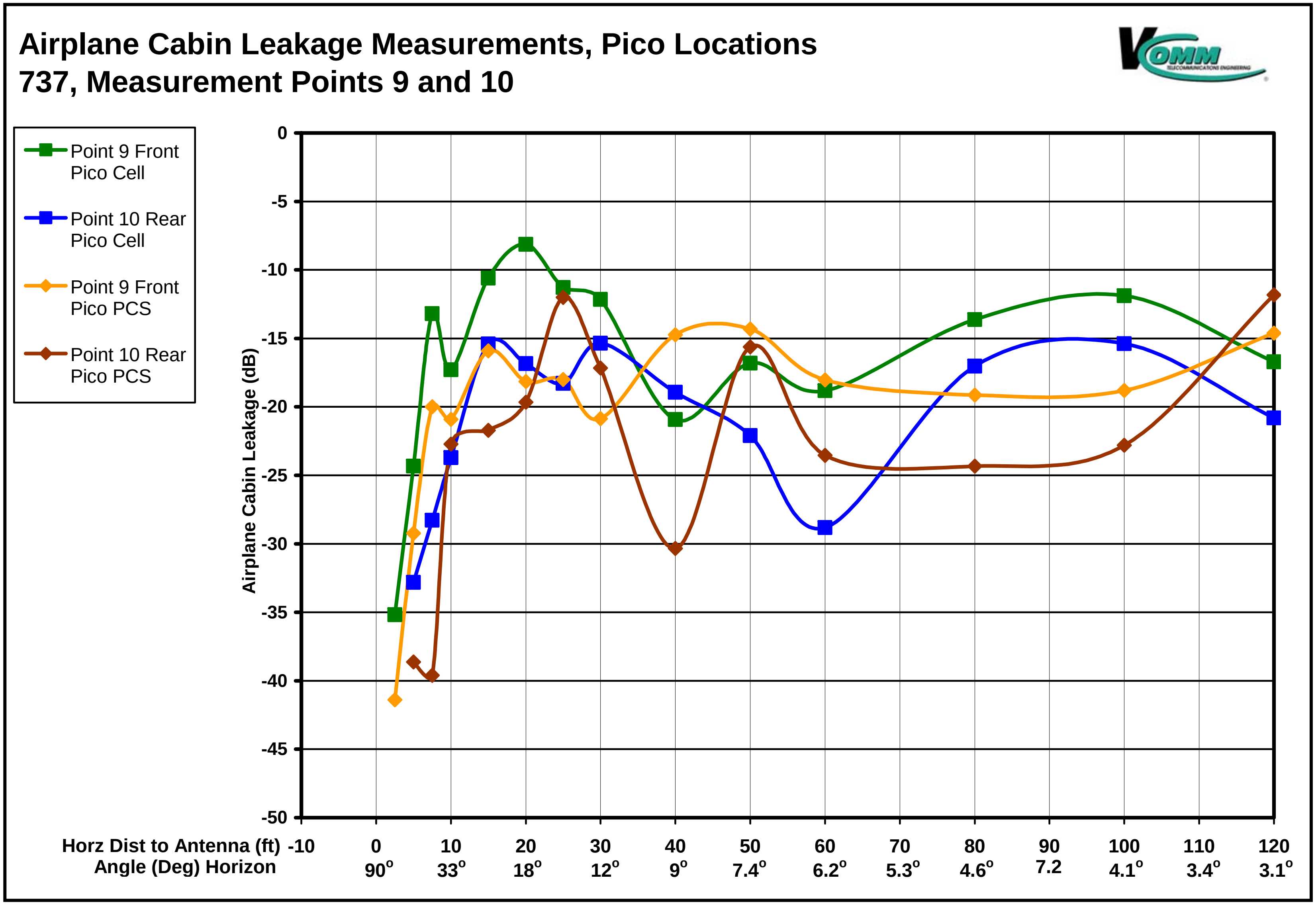

Figure 30, Pico Base Station Measurements, 737

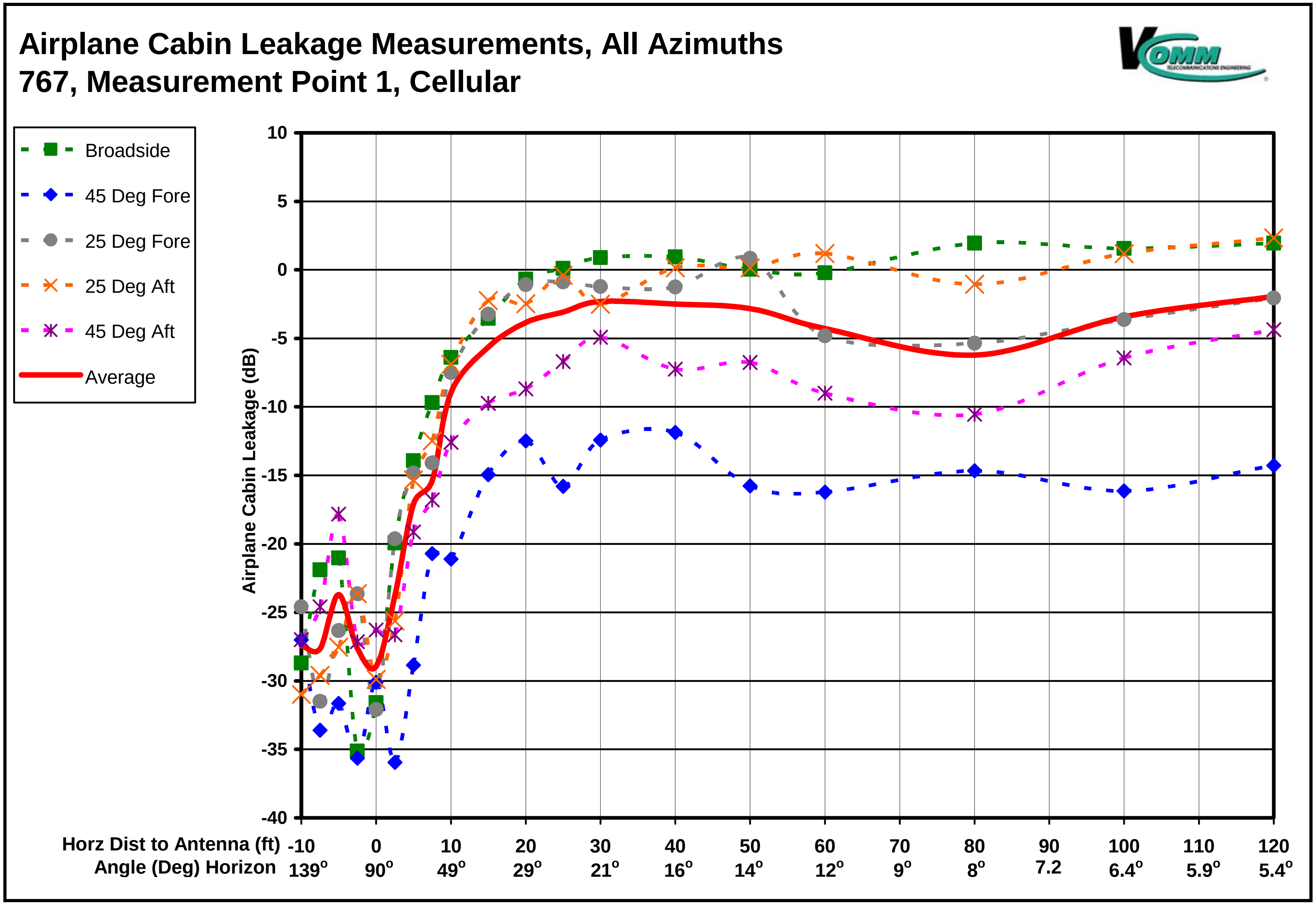

Figure 31, All Azimuth Measurements Point 1, 767 Cellular

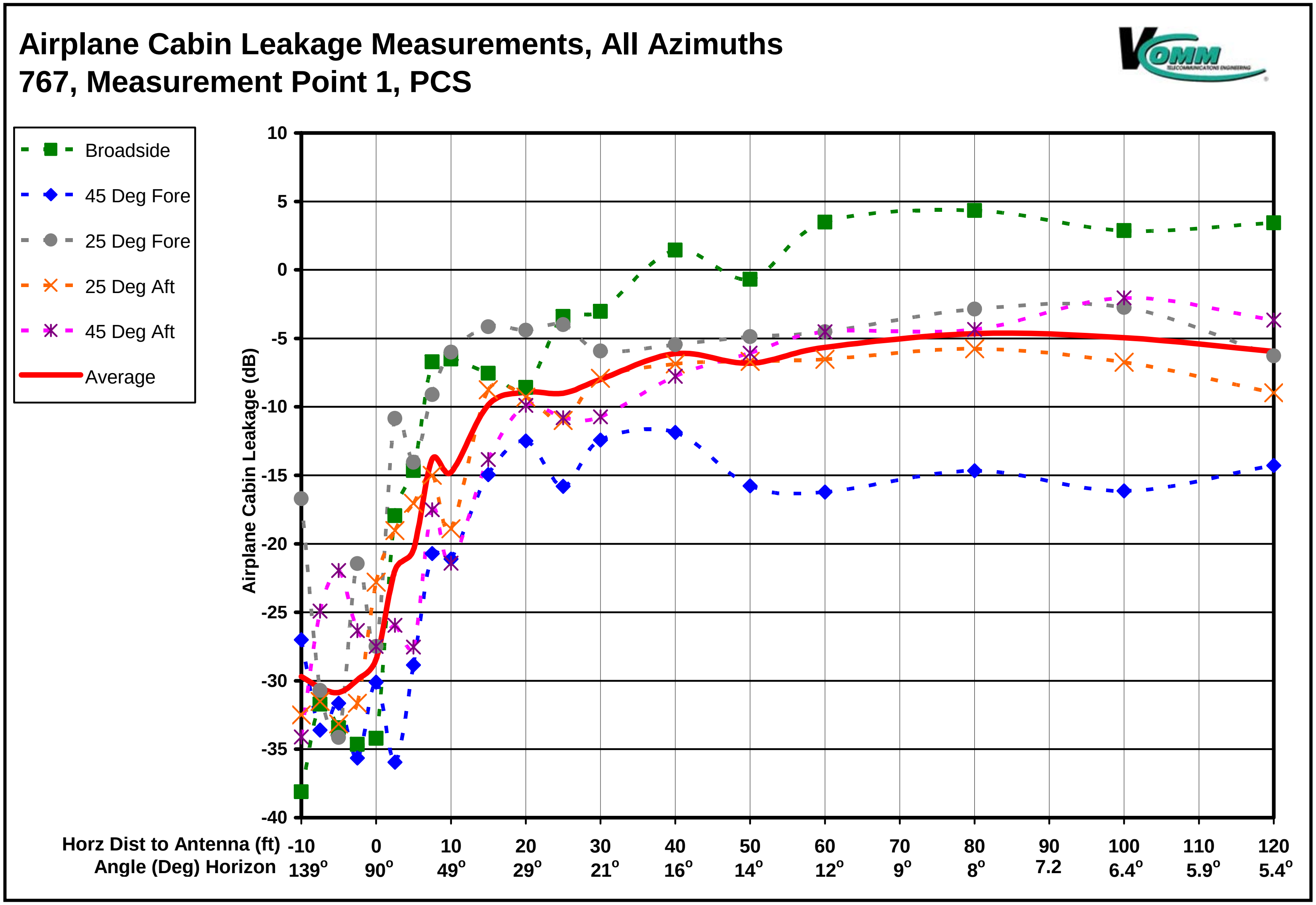

Figure 32, All Azimuth Measurements Point 1, 767 PCS

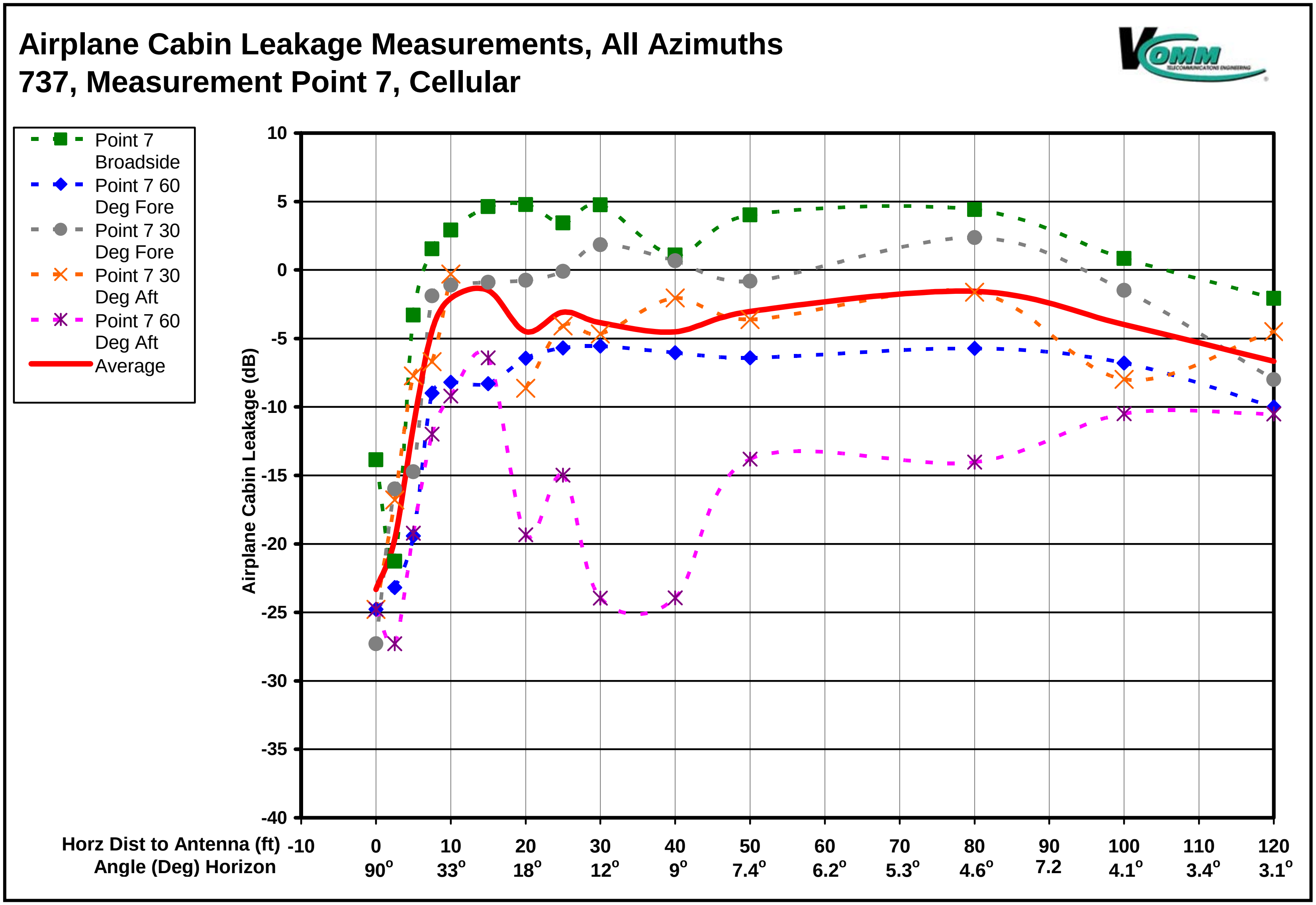

Figure 33, All Azimuth Measurements Point 7, 737 Cellular

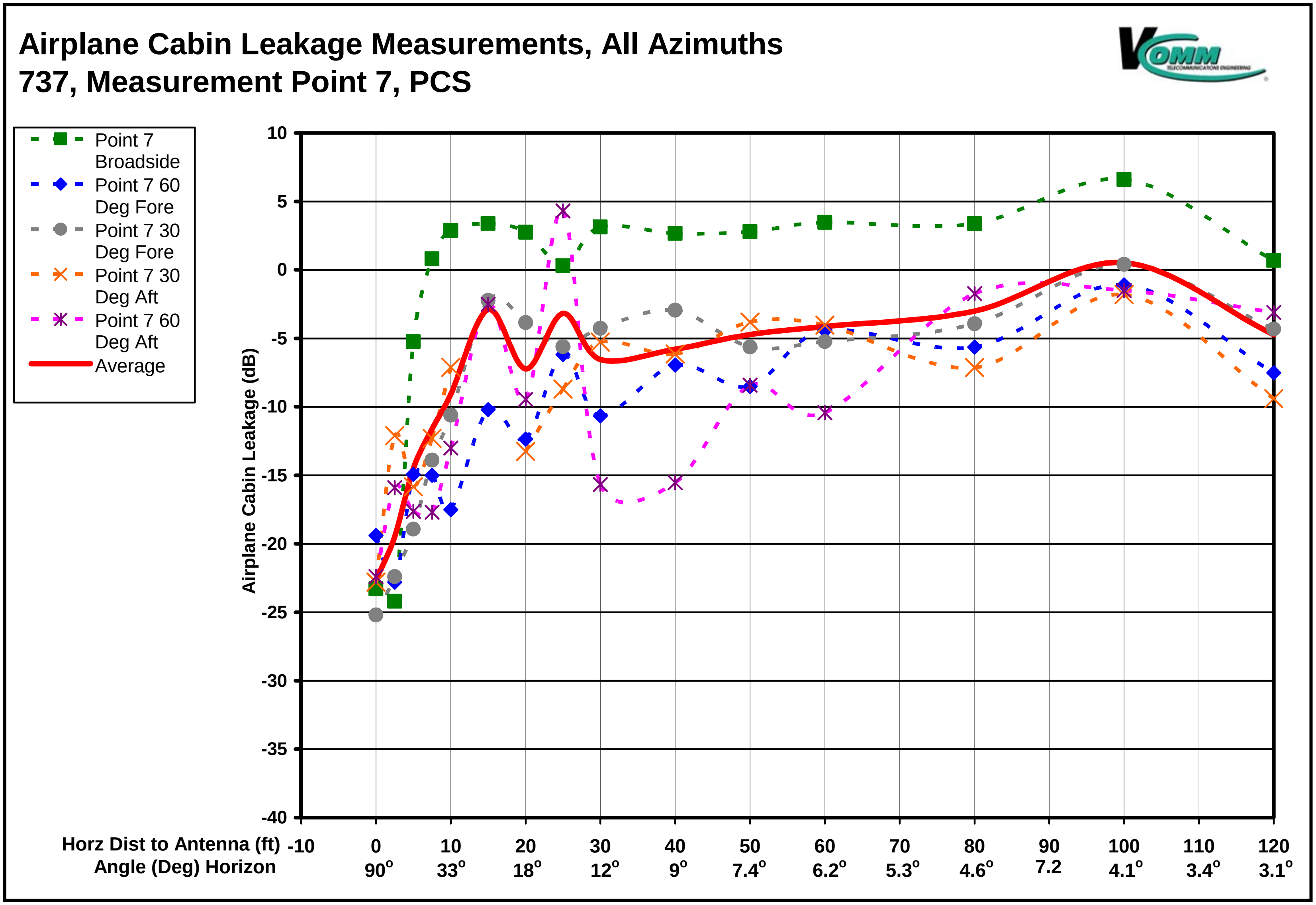

Figure 34 All Azimuth Measurements Points 7, 737 PCS

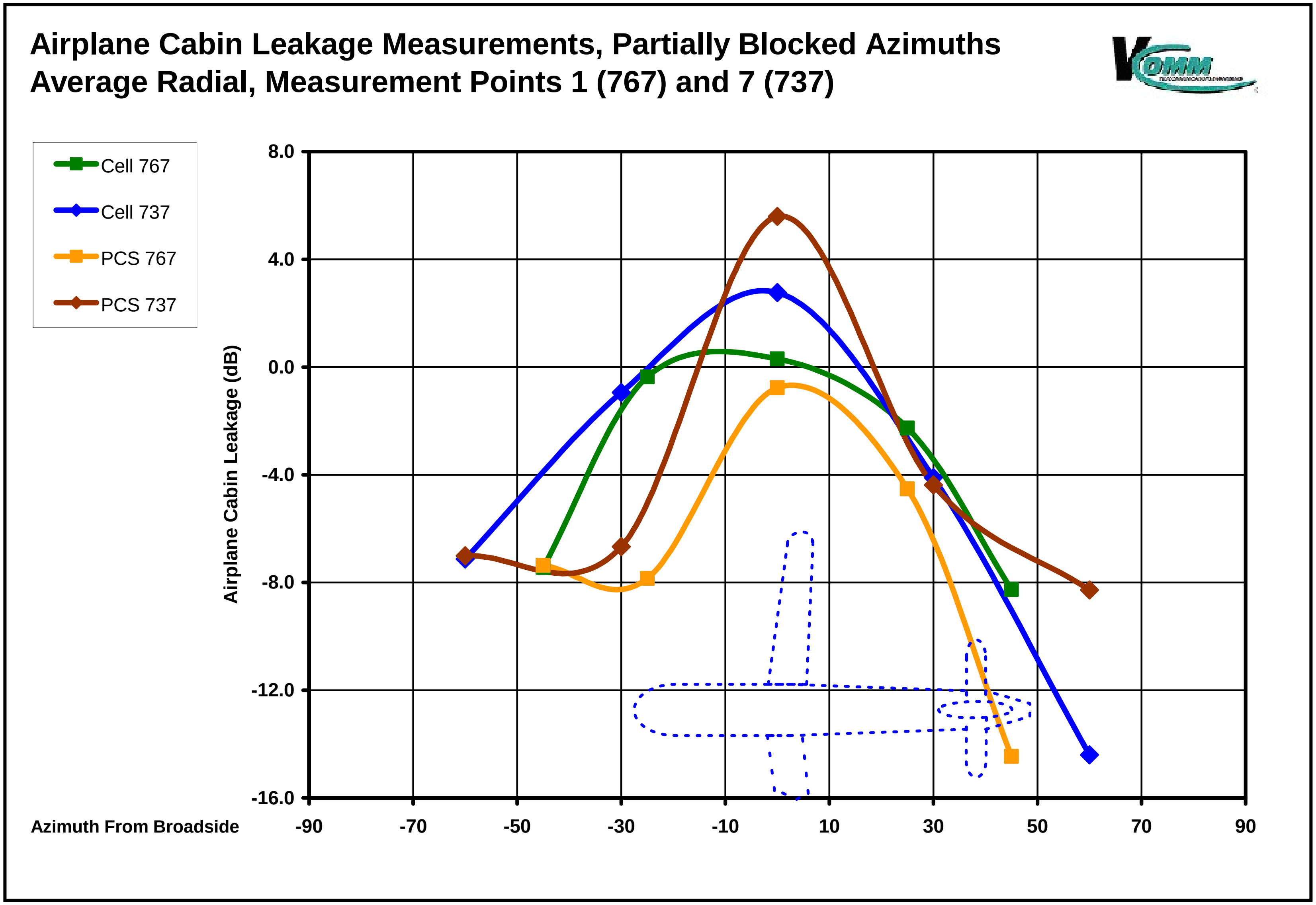

Figure 35 Partially Blocked Azimuth Leakage

7.2. AeroMobile Presentation Slide

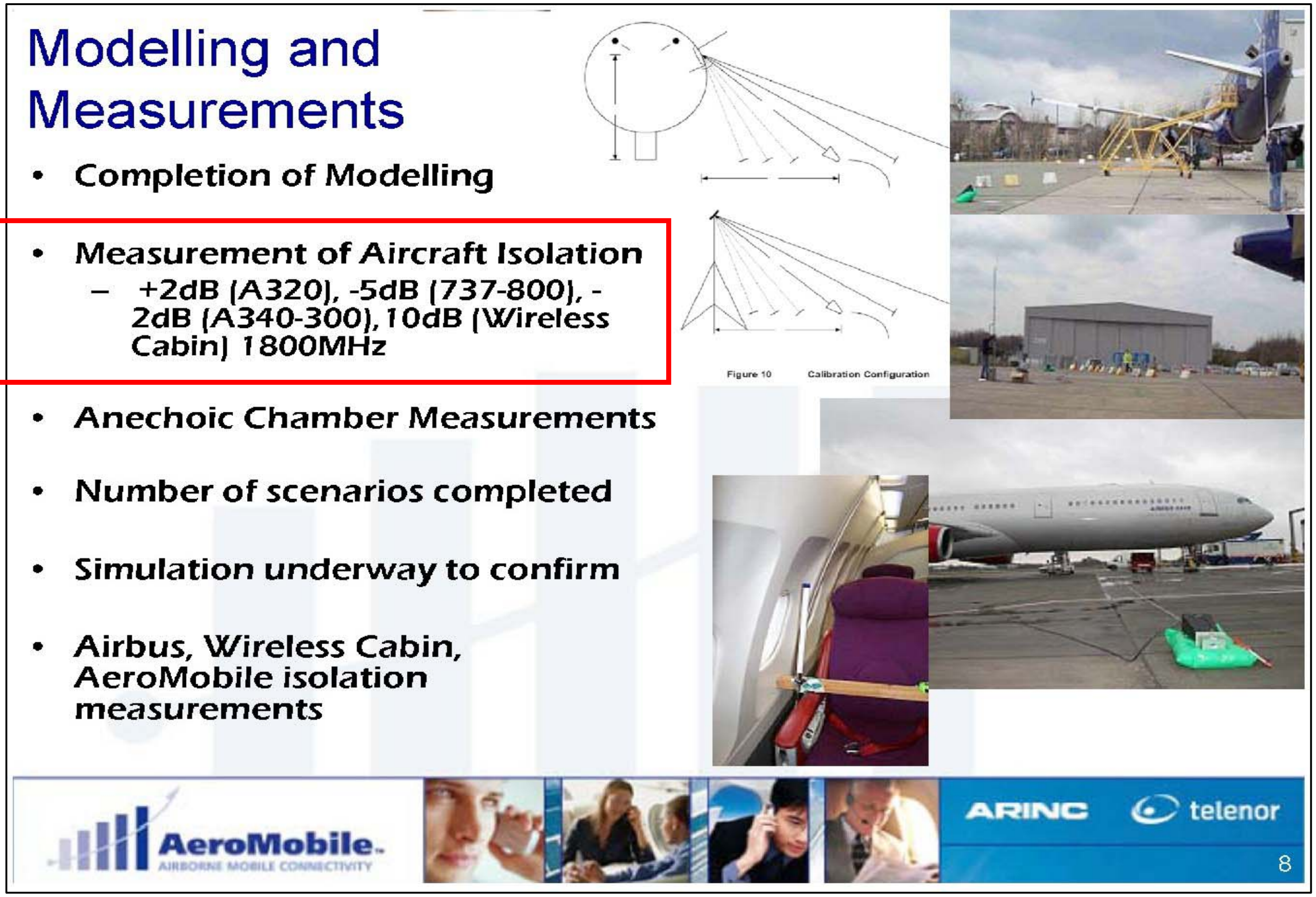

Figure 36, AeroMobile Presentation Slide

7.3. Tested Aircraft History and Specifications

Unless otherwise stated the information provided in this section was obtained from www.AirLiners.net.

Boeing 737-200

The 737 was conceived as a short range small capacity airliner to round out the Boeing jet airliner family beneath the 727, 720 and 707. Announced in February 1965, the 737 was originally envisioned as a 60 to 85 seat, although following consultation with launch customer Lufthansa, a 100 seat design was settled upon. Design features included two under-wing mounted turbofans and 60% structural and systems commonality with the 727, including the same fuselage cross section (making it wider than the competing five abreast DC-9 and BAC-111).

The 737-100 made its first flight on April 9 1967 and entered service in February 1968 with Lufthansa, while the last of 30 built was delivered to Malaysia-Singapore Airlines in October 1969. By this time however the larger capacity 1.93m (6ft 4in) stretched 737-200 was in service after it had made its first flight on August 8 1967. First delivery, to United, was that December.

Boeing 767-200

The narrowest wide-body in service, the 767 started life as an advanced technology mid to large size airliner in the late 1970s. Launched in July 1978, the 767 was developed in tandem with the narrow-body 757 with which it shares a common two crew EFIS flight deck (with six color CRT displays) and many systems. The 767 also features a unique width fuselage typically seating seven abreast in economy, and a new wing design with greater sweepback (compared to the 757) which was designed with high altitude cruise in mind.

The 767 program also features a high degree of international participation, with Japanese companies in particular having a large share of construction. Initially Boeing intended to offer two versions, the longer 767-200 and short fuselage 767-100 (which was not launched as it was too close in capacity to the 757). The 767 first flew on September 26 1981, and entered service (with United) on September 26 1982 (certification with P&W engines was awarded on July 30 1982).

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Airplane Dimension	767-200	737-200
Wing Span	47.57m (156ft 1in)	28.35m (93ft 0in)
Overall Length	48.51m (159ft 2in)	30.53m (100ft 2in)
Height	15.85m (52ft 0in)	11.29m (37ft 0in)
Wing Area	283.3m^2 (3050 ft^2)	91.1m^2 (980 ft^2)
Window Dimensions [4]	12.5 " High X 9.5" Wide	13.5 " High X 9.75 " Wide
Number Built	239	1114

Table 9, Comparison of Tested Aircraft

[4] As measured in the field

7.4. Company Information

V-COMM is a leading provider of quality engineering and engineering related services to the worldwide wireless telecommunications industry. V-COMM's engineering staff is experienced in Cellular, Personal Communications Services (PCS), Enhanced Specialized Mobile Radio (ESMR), Paging, Wireless Data, Microwave, Signaling System 7, and Local Exchange Switching Networks. We have provided our expertise to wireless operators in engineering, system design, implementation, performance, optimization, and evaluation of new wireless technologies. Further, V-COMM was selected by the FCC & Department of Justice to provide expert analysis and testimony in the NextWave and Pocket Communications Bankruptcy cases. V-COMM has offices in Blue Bell, PA and Cranbury, NJ and provides services to both domestic and international markets. For additional information, please visit V-COMM's web site at www.vcomm-eng.com.

7.5. V-COMM, L.L.C. Biographies of Report Authors

Gary Hartman
Senior Engineer

Gary Hartman, Sr. Engineer for V-COMM, has over 29 years of telecommunications engineering experience, including 12 years in the wireless industry from both an engineering and management prospective.

For V-COMM, Mr. Hartman has been involved in both RF engineering and Networking projects for V-COMM's top tier clients, including major wireless carriers and many municipal clients. Mr. Hartman has been the project lead for many of these projects, ranging from the construction of major switching facilities to the development and deployment of custom built performance enhancing equipment for a mobile application. As project lead, his responsibilities require the integration of both the technical and managerial aspects of the projects to bring the projects to a successful completion within the time and budgetary constraints. Mr. Hartman also develops custom engineering computer applications for V-COMM.

Prior to V-COMM Mr. Hartman has worked in both an engineering capacity as well as a management capacity. For PageNet, Mr. Hartman directed the engineering and operations in the New York area, with responsibility for the day to day operations of over 1,000 base stations and 3 switching facilities within the region. Mr. Hartman was also responsible for the Radio Frequency Network design, inter-switch networking, and Interconnection to the Public Switch Telephone Network. While with PageNet, Mr. Hartman represented PageNet at the various state public service commissions in the region regarding Commercial Mobile Radio interconnection with the PSTN and numbering issues. Mr. Hartman finished his career at PageNet as the Director of the Northern Switch Center, a consolidated switching center serving PageNet's customers throughout the Northeast and Midwest. In this position, Mr. Hartman had full operational and budgetary responsibility of the center, serving over 4 million active subscribers.

Prior to PageNet, Mr. Hartman had 17 years of engineering experience in the broadcast industry. During this period, Mr. Hartman designed and constructed numerous FM and TV transmitter facilities and several radio studios, as well as the re-design and re-tuning of several directional AM stations.

Mr. Hartman has a Bachelor of Science, Computer and Information Science, from The Ohio State University.

Sean Haynberg
Director of RF Technologies

Sean Haynberg, Director of RF Technologies at V-COMM, has over 15 years of experience in wireless engineering. Mr. Haynberg has extensive experience in wireless system design, implementation, testing and optimization for wireless systems utilizing CDMA, TDMA, GSM, AMPS and NAMPS wireless technologies. In his career, he has conducted numerous first office applications, compatibility & interference studies, and new technology evaluations to assess, develop and integrate new technologies that meet industry and FCC guidelines. His career began with Bell Atlantic NYNEX Mobile, where he developed an in-depth knowledge of wireless engineering.

While at V-COMM, Mr. Haynberg was responsible for the performance of RF engineering team supplying total RF services to a diverse client group. Projects varied from managing a team of RF Engineers to design and implement new a PCS wireless network in the NY MTA; to the wireless system design & expansion of international markets in Brazil and Bermuda; to system performance testing and optimization for numerous markets in the north and southeast; to the development and procurement of hardware and software engineering tools; to special technology evaluations, system compatibility and interference testing. He has also developed tools and procedures to assist carriers in meeting compliance with FCC rules & regulations for RF Safety, and other FCC regulatory issues. In addition, Mr. Haynberg was instrumental in providing leadership, technical analysis, engineering expertise, and management of a team of RF Engineers to deliver expert-level engineering analysis & reporting on behalf of the FCC & Department of Justice, in the NextWave and Pocket Communications Bankruptcy proceedings.

Prior to joining V-COMM, Mr. Haynberg held various management and engineering positions at Bell Atlantic NYNEX Mobile (BANM). He was responsible for evaluating new technologies and providing support for the development, integration and implementation of first office applications (FOA), including CDMA, CDPD, and RF Fingerprinting Technology. Beyond this, Haynberg provided RF engineering guidelines and recommendations to the company's regional network operations, supported the deployment and integration of new wireless equipment and technologies, including indoor wireless PBX/office systems, phased/narrow-array smart antenna systems, interference and inter-modulation analysis and measurement, and cell site co-location and acceptance procedures. He was responsible for the procurement, development and support of engineering tools for RF, network and system performance engineers to enhance the system performance, network design and optimization of the regional cellular networks. He began his career as an RF Engineer responsible for the system design and expansion of over 100 cell sites for the cellular markets in New Jersey, Philadelphia, PA; Pittsburgh, PA; Washington, DC; and Baltimore, MD market areas.

Mr. Haynberg earned a Bachelor of Science degree in Electrical Engineering with high honors, and attended post-graduate work, at Rutgers University in Piscataway, New Jersey. While at Rutgers, Mr. Haynberg received numerous honors including membership in the National Engineering Honor Societies Tau Beta Pi and Eta Kappa Nu. In addition, Mr. Haynberg has qualified and provided expert witness testimony in the subject matter of RF engineering and the operation of wireless network systems for many municipalities in the State of New Jersey.

Dominic C. Villecco
President and Founder

Dominic Villecco, President and founder of V-COMM, is a pioneer in wireless telecommunications engineering, with 22 years of executive-level experience and various engineering management positions. Under his leadership, V-COMM has grown from a start-up venture in 1996 to a highly respected full-service consulting telecommunications engineering firm.

In managing V-COMM's growth, Mr. Villecco has overseen expansion of the company's portfolio of consulting services, which today include a full range of RF & Network design, engineering & support; network design tools; measurement hardware; and software services; as well as time-critical engineering-related services such as business planning, zoning hearing expert witness testimony, regulatory advisory assistance, and project management.

Before forming V-COMM, Mr. Villecco spent 10 years with Comcast Corporation, where he held management positions of increasing responsibility, his last being Vice President of Wireless Engineering for Comcast International Holdings, Inc. Focusing on the international marketplace, Mr. Villecco helped develop various technical and business requirements for directing Comcast's worldwide wireless venture utilizing current and emerging technologies (GSM, PCN, ESMR, paging, etc.).

Previously he was Vice President of Engineering and Operations for Comcast Cellular Communications, Inc. His responsibilities included overall system design, construction and operation, capital budget preparation and execution, interconnection negotiations, vendor contract negotiations, major account interface, new product implementation, and cellular market acquisition. Following Comcast's acquisition of Metrophone, Mr. Villecco successfully merged the two technical departments and managed the combined department of 140 engineers and support personnel.

Mr. Villecco served as Director of Engineering for American Cellular Network Corporation (AMCELL), where he managed all system implementation and engineering design issues. He was responsible for activating the first cellular system in the world utilizing proprietary automatic call delivery software between independent carriers in Wilmington, Delaware. He also had responsibility for filing all FCC and FAA applications for AMCELL before it was acquired by Comcast.

Prior to joining AMCELL, Mr. Villecco worked as a staff engineer at Sherman and Beverage (S&B), a broadcast consulting firm. He designed FM radio station broadcasting systems and studio-transmitter link systems, performed AM field studies and interference analysis and TV interference analysis, and helped build a sophisticated six-tower arrangement for a AM antenna phasing system. He also designed and wrote software to perform FM radio station allocations pursuant to FCC Rules Part 73.

Mr. Villecco started his career in telecommunications engineering as a wireless engineering consultant at Jubon Engineering, where he was responsible for the design of cellular systems, both domestic and international, radio paging systems, microwave radio systems, two-way radio systems, microwave multipoint distribution systems, and simulcast radio link systems, including the drafting of all FCC and FAA applications for these systems.

Mr. Villecco has a BSEE from Drexel University, in Philadelphia, and is an active member of IEEE. Mr. Villecco also serves as an active member of the Advisory Council to the Drexel University Electrical and Computer Engineering (ECE) Department.

Relevant Expert Witness Testimony Experience:

Over the past five years, Mr. Villecco had been previously qualified and provided expert witness testimony in the states of New Jersey, Pennsylvania, Delaware and Michigan. Mr. Villecco has also provided expert witness testimony in the following cases:

- United States Bankruptcy Court

- NextWave Personal Communications, Inc. vs. Federal Communications Commission (FCC) **

- Pocket Communications, Inc. vs. Federal Communications Commission (FCC) **

** In these cases, Mr. Villecco was retained by the FCC and the Department of Justice as a technical expert on their behalf, pertaining to matters of wireless network design, optimization and operation.